Mechanical and chemical thinning of stone fruit

By

Michiel Hendrik Jacobus de Villiers

Thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Agriculture (Horticultural Science) at the University of Stellenbosch

Supervisor:

Prof Karen I. Theron

Dept. of Horticultural Science

University of Stellenbosch

Co-supervisor:

Prof Wiehann Steyn

Dept. of Horticultural Science

University of Stellenbosch

December 2014

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:

Acknowledgements

I firstly want to thank my heavenly Father for the strength, belief and guidance He gave me to finish this thesis. When times were tough He helped me to push through.

To prof. Karen, thank you for your patience with me. I know that writing is not one of my talents and you had to endure it from the start, but hopefully it improved as we worked through the thesis. Thank you also for all the advice you gave me for the thesis and with my work going forward. I would also like to thank Wiehann Steyn for being the second pair of eyes to look at my work. Your insight and help with the thesis was also appreciated.

I thank the South African Stone Fruit Producers Association for funding my project and giving me a bursary. To Southtrade for ensuring that the machine was always there on time and set up on the tractor. I thank all the farmers who gave me access to their farms to perform the trials and gather information. These farms includes: Swartdam where Oom Louw and Deon van Zyl assisted me, Tandfontein where the farm manager Klasie was always a helping hand, even when we forgot the plastic bags. Thank you to Hannes Laubscher from Dutoit Agri who helped organise the trials on Swartdam and Tandfotein. In Simondium, Oom Daan on the farm Klein-Simonsvlei and Stefan on the farm Babylonstoren, thank you for providing me with people to perform the trials quick and easy. Lastly, Willem on the Welgevallen research farm was always a helping hand with the harvesting of trials.

Thank you to all the technical staff and Gustav Lötze who helped with my trials. Thank you to Tikkie and André for the early morning driving to Tandfontein and to all the laboratory ladies, Shantel, Poena, Deen and Vona who helped me with analysing the fruit.

To Philna, thank you for all the motivation, the belief in me that I can do the work and helping me keep calm when I felt things were getting too big for me. Thank you to my parents for always having encouraging words and always being there for me when finances were low. Thank you to all my friends who had coffee with me whenever I was too lazy to work.

Summary

Producing fruit of the appropriate size and high quality is of the upmost importance to realize a profit in the fruit industry. This can be achieved through bloom or fruitlet thinning to reduce the number of fruit left on the tree. The cost of production is rising and labour cost forms a large part of the total production cost. Thinning of stone fruit is labour intensive and expensive, so an alternative to hand thinning needs to be found. Two alternatives are chemical and mechanical thinning. Chemical thinners are not routinely used in stone fruit as it is in pome fruit production and gibberellins were evaluated in this study. The Darwin 300™ was evaluated as a mechanical alternative to hand thinning. It thins flowers during bloom, before fruitlet thinning by hand is performed. In our trials on nectarines and Japanese plums the objective of reducing the time required for hand thinning was achieved, with the Darwin 300™ reducing the time required by up to 50%. When the time required to thin was reduced too much it also reduced the yield, but this could be overcome by lowering the rotor speed or using different strategies during supplementary hand thinning at the fruitlet stage. The bloom thinning and reduction in yield led to an increase in the fruit size. Care should be taken when using the Darwin 300™ as the earlier thinning could increase pit splitting and/or fruit cracking, especially in cultivars that are sensitive to these defects. The optimal rate of thinning needs to be determined for each cultivar individually. The application of gibberellic acid (GA_3) and gibberellin A_{4+7} (GA_{4+7}) at the pit hardening stage in the previous season could decrease the number of flowers for the following growing season. There was no effect on the yield at harvest or fruit size in the season of GA_3 and GA_{4+7} applications, but the fruit firmness was increased. This effect was more pronounced for the GA_{4+7} applications. Our objective of reducing the time required for thinning was achieved in some but not all cultivars. The yield was not significantly reduced, with the fruit maturity only delayed in 'African Rose' plum. Again no increase in fruit size was found, but the fruit firmness was again increased. The GA-applications therefore were not satisfactory in their reduction of the time required for hand thinning. A positive effect is the increase in fruit firmness, which could possibly increase the storage potential of the fruit without having negative effects on the other aspects of fruit quality but this needs further evaluation.

Opsomming: Meganiese en chemiese uitdunning van steenvrugte

Produksie van vrugte met die verlangde vruggrootte en hoë vrug kwaliteit is baie belangrik vir die realisering van 'n wins in die vrugte-industrie. Met hierdie mikpunt in gedagte, is blom- en vruguitdunning baie belangrik om die aantal vrugte per boom te verminder. Die kostes geassosieer met vrugte produksie is besig om te styg en arbeidskoste vorm 'n groot deel van die totale produksiekostes. Uitdunning van steenvrugte is arbeidsintensief en baie duur, dus moet 'n alternatief vir handuitdunning gevind word. Daar is twee alternatiewe naamlik chemiese en meganiese uitdunning. Chemiese uitdunmiddels word algemeen in kernvrugproduksie gebruik, maar daar is tans geen chemiese middels vir steenvrugte nie. In hierdie studie was gibberelliene ge-evalueer as potensiële uitdunmiddel. Die Darwin 300™ is ge-evalueer gedurende blomtyd as 'n meganiese alternatief vir handuitdunning. Die masjien verwyder blomme en verminder so die vruguitdunning benodig. In ons eksperimente op nektarien- en Japanese pruimkultivars het ons gevind dat die tyd benodig vir handuitdunning met tot 50% verminder is deur die Darwin 300™. Dit het ook daartoe gelei dat die totale oes per boom verlaag is. Hierdie effek kan vermy word deur die rotor spoed te verminder of die strategie vir aanvullende handuitdunning aan te pas. Die feit dat die grootste deel van die uitdunproses in blomtyd uitgevoer is en ook die feit dat die totale oes per boom verlaag is, het daartoe gelei dat die vrugte groter was. Die vroeër uitdunning met die Darwin 300™ kan egter lei tot 'n verhoging in vrugkrake en gesplete pitte. Dit moet veral in gedagte gehou word by kultivars wat geneig is tot hierdie afwykings/defekte. Die optimum tempo van uitdunning moet vir elke kultivar individueel bepaal word. Wanneer gibberelliensuur (GA_3) of gibberelien A4+7 (GA_{4+7}) by pitverharding toegedien word in die vorige groeiseisoen, kan dit lei tot die vermindering van die hoeveelheid vrugte in die volgende seisoen. Daar was geen effek op die totale oes per boom en die vruggrootte tydens oes in die seisoen van aanwending nie, maar die vrugfermheid is verhoog. Die effek was hoër na die GA_{4+7} as na die GA_3 aanwending. Die mikpunt om die tyd benodig vir handuitdunning te verminder, is in sommige kultivars bereik. Die oes per boom in die opvolgseisoen is weer eens nie verlaag nie, maar die vrug rypheid van 'African Rose' pruime is vertraag. Geen effek is op die vruggrootte opgemerk nie, maar die vrugfermheid was weer eens verhoog. Die GA-toedienings het dus nie bevredigend die tyd benodig vir handuitdunning verminder nie. 'n Positiewe effek is die verhoging van die vrugfermheid, wat moontlik kan lei tot die verhoging van die opbergingspotensiaal van die vrugte sonder enige ander negatiewe effekte, maar hierdie aspek benodig verdere navorsing.

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 the *Southern African Journal for Plant and Soil*. Repetition or duplication between papers might therefore be nessecary.

Table of Contents

General introduction

A profitable crop is defined as a crop with high fruit quality and fruit weight along with a marketable volume (Costa and Vizzotto 2000). To achieve this, thinning is required as only ±7% of the flowers produced at bloom is required to set an economical crop (Solomakhin and Blanke 2010, Hehnen et al. 2012). If thinning is therefore performed, it results in increased fruit size (Wertheim 1997; Dennis 2000) and quality of the remaining fruit (Wertheim 1997, Costa and Vizzotto 2000). The increase in fruit quality includes higher sugar, firmness, phenols and vitamin C content (Seehuber et al. 2011). Other responses to thinning include the advancement of fruit maturity, promotion of reproductive bud induction and the improvement of the fruit-to-shoot ratio (Costa and Vizzotto 2000). This will all lead to the maximization of crop value (Byers 1989, Reighard and Byers 2009). Therefore for most commercial peach, apricot, prune, plum and nectarine cultivars, thinning is of high importance (Southwick and Glozer 2000). Thinning in stone fruit is mostly still performed by hand (Rosa et al. 2008), which largely contributes to the total production cost. This is because hand thinning is very labour intensive (Baugher et al. 2009) and the cost of labour is increasing (Costa and Vizzotto 2000). The thinning performed by hand is effective, but requires a lot of time (González-Rossia et al. 2007). Locations and cultivars differ, which along with season, influences the decision and severity of thinning (Schupp et al. 2008). Alternatives to hand thinning include chemical and mechanical thinning (Rosa et al. 2008).

In the literature study the current literature on stone fruit thinning is summarised. Mechanical thinning is an environmentally friendly method of thinning that producers can use to thin their trees (Solomakhin and Blanke 2010). This is a big advantage compared to chemical thinning. Chemical thinners for stone fruit are also scarce and/or often ineffective (Solomakhin and Blanke 2010, Seehuber et al. 2011). Products registered for stone fruit are also being phased out. Another advantage of mechanical thinners is that the thinning effect can be observed while thinning is performed; therefore adjustments can also be made to the thinning intensity while thinning (Byers 1989, Baugher et al. 2009). A wide variety of mechanical thinners have been evaluated over the past few years. These includes labourers with rakes, trunk-shakers (Reighard and Byers 2009), low-frequency electrodynamic limb shakers (Rosa et al. 2008), high-pressure water streams (Byers et al. 2003; Reighard and Byers 2009), rope curtains (Baugher et al. 1991), rotating curtains (Baugher et al. 1991; Schupp et al. 2008), spike-drums (Glen et al. 1994, Baugher et al. 2008) and impact shakers (Schupp et al. 2008). The Darwin was originally called a wire-machine (Bertschinger et al. 1998) and was developed by an organic apple grower to thin apple trees during bloom (Baugher et al. 2010).

The machine is mounted on the tractor (Baugher et al. 2009) and is driven by the tractor's hydraulic system (Schupp et al. 2008, Baugher et al. 2010, Schupp and Baugher 2011). It has a vertical three meter spindle (Schupp et al. 2008, Baugher et al. 2010, Schupp and Baugher 2011) and attached to the spindle are 36 steel plates securing 648, 50 cm long plastic cords (Schupp et al. 2008, Ngugi and Schupp 2009, Baugher et al. 2010). The chemical thinning options for stone fruit are limited (Schupp et al. 2008), while in pome fruit effective chemical thinners are readily available. If a chemical thinner for stone fruit is found, it should be quick, easy and relatively inexpensive to use (González-Rossia et al. 2007). Chemical thinners could be applied at bloom or the fruitlet stage in the current growing season (Wertheim 1997), or as in our case, gibberellins are applied in the previous growing season to reduce flower induction (Southwick et al. 1995, González-Rossia et al. 2007). The induction period is around the pit hardening stage of fruit growth (Southwick and Glozer 2000, Reighard and Byers 2011). There are other beneficial effects of applying the gibberellins, e.g. an improvement of fruit quality, delaying harvest and improving the storability of fruit in the application season (Lurie 2010). It can also result in fruit being firmer and heavier (Lurie 2010). The gibberellin application in the induction period would therefore result in a decrease in flower bud production and therefore reduce the requirement for hand thinning the following season.

Removing unwanted fruit with the most cost effective method as early as possible is the aim of our study. In Paper 1 we report on mechanical thinning trials performed on nectarines while in Paper 2, we report on mechanical thinning trials on Japanese plums. The efficiency of the Darwin 300™ as a bloom thinner to reduce the requirement for hand thinning and the effect on fruit size and quality was determined. The nectarine cultivars were Zephyr and Summer Fire from the farm Tandfontein, in the Koue Bokkeveld area, South Africa (2011/2012 and 2012/2013 seasons) and Royal Sun from the farm Swartdam, near Riebeeck-Kasteel, South Africa (2012/2013 season). The trials on Japanese plums were performed at the Welgevallen research farm in Stellenbosch, South Africa, during the 2011/2012 season on the cultivar Laetitia and in the 2012/2013 season, trials were performed on the cultivar African Rose on the farm Klein-Simonsvlei and on African Delight on the farm Babylonstoren, both in Simondium, South Africa.

In Paper 3 we report on the chemical trials where two commercial gibberellin containing products were evaluated to determine their efficacy in reducing flower induction and consequent reduction of hand thinning time, while maintaining the fruit quality in Japanese plums. The Japanese plum cultivars Laetitia and Larry Ann were used at the Welgevallen research farm, in the Stellenbosch area, South Africa over the 2011/2012 and 2012/2013 seasons. During 2012/2013, trials were also performed on 'Pioneer', on the farm Klein-Simonsvlei and 'African Rose' on the farm Babylonstoren, Simondium, South Africa.

Literature cited

Baugher TA, Elliott KC, Leach DW, Horton BD, Miller SS. 1991. Improved methods of mechanically thinning peaches at full bloom. *Journal of the American Society for Horticultural Science* 116(5): 766-769.

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

Baugher TA, Schupp JR, Lesser KM, Hess-Reichard K. 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 TA, Schupp J, Miller S, Harsh M, Lesser K, Reichard K, Sollenberger E, Armand M, Kammerer L, Reid M, Rice L, Waybright S, Wenk B, Tindall M, Moore E. 2008. Chemical and mechanical thinning of peaches. *Pennsylvania Fruit News* 88: 16-17.

Bertschinger L, Stadler W, Stadler P, Weibel F, Schumacer R. 1998. New methods of environmentally safe regulation of flower and fruit set and of alternate bearing of the apple crop. *Acta Horticulturae* 466: 65-70.

Byers RE. 1989. Response of peach trees to bloom thinning. *Acta Horticulturae* 254: 125-132.

Byers RE, Costa G, Vizzotto G. 2003. Flower and fruit thinning of peach and other *Prunus*. *Horticultural Reviews* 28: 351-490.

Costa G, Vizzotto G. 2000. Fruit thinning of peach trees. *Plant Growth Regulation* 31: 113-119.

Dennis Jr. FG. 2000. The history of fruit thinning. *Plant Growth Regulation* 31: 1-16.

Glenn DM, Peterson DL, Giovannini D, Faust M. 1994. Mechanical thinning of peaches is effective postbloom. *HortScience* 29(8): 850-853.

González-Rossia D, Reig C, Juan M, Agustí M. 2007. Horticultural factors regulating effectiveness of GA_3 inhibiting flowering in peaches and nectarines (*Prunus persica* L. Batsch). *Scientia Horticulturae* 111: 352-357.

Hehnen D, Hanrahan I, Lewis K, Mcferson J, Blanke M. 2012. Mechanical flower thinning improves fruit quality of apples and promotes consistent bearing. *Scientia Horticulturae*. 134: 241-244.

Lurie S. 2010. Plant growth regulators for improving postharvest stone fruit quality. *Acta Horticulturae* 884: 189-198.

Ngugi HK, Schupp JR. 2009. Evaluation of the risk of spreading fire blight in apple orchards with a mechanical string blossom thinner. *HortScience* 44(3): 862-865.

Reighard GL, Byers RE. 2009. Peach thinning. Available at

www.ent.uga.edu/peach/peachhbk/cultural/thinning.pdf.

Rosa UA, Cheetancheri KG, Gliever CJ, Lee SH, Thompson J, Slaughter DC. 2008. An electro-mechanical limb shaker for fruit thinning. *Computers and electronics in agriculture* 61: 213-221.

Schupp JR, Baugher TA. 2011. Peach blossom string thinner performance improved with selective pruning. *HortScience* 46(11): 1486-1492.

Schupp JR, Baugher TA, Miller SS, Harsh RM, Lesser KM. 2008. Mechanical thinning of peach and apple trees reduces labor input and increases fruit size. *HortTechnology* 18(4): 660-670.

Seehuber C, Damegrow L, Blanke M. 2011. Regulation of source: sink relationship, fruit set, fruit growth and fruit quality in European plum (*Prunus domestica* L.)-using thinning for crop load management. *Plant Growth Regulation* 65: 335-341.

Solomakhin AA, Blanke MM. 2010. Mechanical flower thinning improves the fruit quality of apples. *Journal of Science of Food and Agriculture* 90: 735-741.

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

Wertheim SJ. 1997. Chemical thinning of deciduous fruit trees. *Acta Horticulturae* 463: 445-462.

LITERATURE REVIEW: MECHANICAL AND CHEMICAL THINNING OF STONE FRUIT

Table of Contents

Introduction

A variety of fruit types are classified as stone fruit or drupes. This includes the non-climacteric cherry and the apricot (Lurie 2010). The other fruit types that are part of the deciduous stone fruit group are nectarines, peaches and plums, which all ripen during summer (Lurie 2010). In 2012, the worldwide production of stone fruit (*Prunus* spp.) was 36.7 million tons (Hortgro 2012). Cultivars currently used in production are high fertile, thus set more fruit than needed for an economical crop (Costa and Vizzotto 2000). Only ±7% of the flowers at bloom are generally required to set an economical crop (Solomakhin and Blanke 2010, Hehnen et al. 2012) and for this reason thinning of flowers or fruitlets is a necessity to achieve a profitable crop.

Thinning has been practised for hundreds of years and it serves various purposes. It improves fruit size (Wertheim 1997, Dennis 2000), leaf size, prevents breakage of limbs, improves fruit quality (Costa and Vizzotto 2000), improves return bloom, prevents exhaustion of tree reserves and reduces cold hardness (Dennis 2000). The extent to which these effects can be achieved through thinning is dependent on the severity and timing of thinning.

In this literature review the effect of thinning, timing of thinning and methods of thinning stone fruit will be discussed.

Effect of thinning

Fruit thinning influences the partitioning of carbohydrates, promotes vegetative growth, and affects the induction and differentiation of the floral buds (González-Rossia et al. 2006). The positive effects of thinning are well known. A reduction in the number of fruitlets or flowers on the tree will result in an increase in the fruit size (Wertheim 1997, Dennis 2000) and quality of the remaining fruit (Wertheim 1997, Costa and Vizzotto 2000). Fruit quality improvements include higher sugar, firmness, phenols and vitamin C, which can be explained by the reduction in the competition for the available assimilates between fruit (Seehuber et al. 2011). Fruit growth is thus dependent on the relationship between the number of fruit and leaves, and the amount of assimilates, either from stored reserves from the previous season or current assimilates produced by photosynthesis (Byers 1989, Damegrow and Blanke 2009). Individual fruit weight is increased and the fruit maturity advanced, reproductive bud induction is promoted and fruit-to-shoot ratio improved (Costa and Vizzotto 2000). In addition, the cost of harvest is reduced, because there are fewer, larger fruit per tree (Rosa et al. 2008). These factors lead to the maximization of crop value, with a reduction or elimination of alternate bearing, while maintaining vegetative development and tree structure (Byers 1989, Reighard and Byers 2009).

When these advantages are quantified into economic terms, the higher fruit quality and fruit weight should lead to an increase in the value of the crop (Costa and Vizzotto 2000). The market price typically depends on the fruit size, but orchard profitability also includes the number of economically marketable fruits, the number of cartons packed per orchard and the value per unit (Reighard and Byers 2009). Most markets currently demand large fruit (Seehuber et al. 2011). Thinning is therefore important for the production of a high value crop. However, it should be remembered that the determination of the optimal crop load, thus the number of fruit after thinning, is dependent on the market price for larger fruit, the potential of the tree to produce large fruit and high yields, and the effect of different cultivation methods on fruit and tree growth (Byers 1989, Reighard and Byers 2009). González-Rossia et al*.* (2007) found that 80% of the variation in final fruit size could be explained by variation in the initial fruit number on the tree (González-Rossia et al. 2007). Natural fruit drop periods should also be kept in mind. These periods will usually not reduce the crop load to the correct level, but could decrease the crop load significantly. Fruit that drop during these periods are normally unfertilized fruit, fruit with aborted embryos due to cold injuries, or due to competition between fruit or too much shading (Reighard and Byers 2009). There are three major periods where natural fruit drop can take place after initial fruit set (Reighard and Byers 2009). The first period is at stage II of fruit growth (25 days after full bloom (dafb)), when unfavourable conditions at bloom led to poor pollination or fertilization (Reighard and Byers 2009). These unfertilized fruit will normally grow till 25-50 dafb, where after growth will slow down and abscissions will take place. However, the depletion of reserves has already taken place, thus removing these unwanted fruit earlier would be desirable (Reighard and Byers 2009). The second period of natural fruit drop is “June” drop (30-50 dafb). Here fertilized fruit will be abscised because of competition for photosynthates between fruitlets (Reighard and Byers 2009). A third period where natural fruit drop could take place is a shade-induced drop between 30-50 dafb that can be induced by three to four days of heavily overcast conditions (Reighard and Byers 2009).

Cultivars that set heavy crop loads will benefit more from thinning than cultivars that produce fewer flowers or set fewer fruit (Byers 1989). European plum trees (Seehuber et al. 2011), but more so peach trees (Schupp and Baugher 2011), are particularly affected by the negative effects of over cropping, which include poor quality fruit (Seehuber et al. 2011, Schupp and Baugher 2011) and a decrease in the longevity of the tree (Rosa et al. 2008). Stone fruit benefit more from bloom thinning than pome fruit (Southwick and Glozer 2000) for the following six reasons according to

Seehuber et al. (2011): Stone fruit primary leaves are absent at the time of thinning unlike in apples and the fruit usually develop over a shorter period. Stone fruit also do not exhibit "June drop", but may have a severe pre-harvest drop. The threshold that has to be exceeded before the fruit grow faster and final fruit weight and sugar increase is much lower than in pome fruit. Another problem is that the upper saturation threshold for fruit growth, i.e. the level of thinning above which no further gain in fruit size is achieved, is reached at 60% removal, which is a relatively low level of thinning. Removal of more fruit will not result in a further gain in fruit size. Crop load and therefore source: sink relationships, are difficult to manipulate in stone fruit, as stone fruit fail to react to chemical treatments that easily thin pome fruit (Seehuber et al. 2011). The reason for this is that the efficacy of chemical thinners, in stone fruit, differs per crop, orchard and also season (Schupp et al. 2008).

Considering the above, thinning is a necessity in most commercial peach, apricot, prune, plum and nectarine cultivars (Southwick and Glozer 2000). It is still mostly done by hand (Rosa et al. 2008). Hand thinning contributes largely to the production costs of stone fruit. The reason for this is that hand thinning is labour intensive (Baugher et al. 2009). In addition, labour is becoming more difficult to obtain (Damegrow and Blanke 2009), unproductive in certain areas (Baugher et al. 2009) and therefore costs are increasing (Costa and Vizzotto 2000). Therefore, although hand thinning is effective in reducing the number of flowers or fruitlets, between 100 and 500 hours of labour per hectare are required, depending on tree size, flower density and thinning intensity required (González-Rossia et al. 2007).

Timing of thinning

The necessity for thinning was discussed in the previous section, but the timing of thinning also has a profound influence on the efficiency of thinning (Costa and Vizzotto 2000). Unwanted fruit should be removed as early as possible, using the most cost effective method possible (Reighard and Byers 2009). Thus, the longer unwanted fruit are on the tree, the bigger their adverse influence (Reighard and Byers 2009). Still, it should be remembered that location and cultivars differ, which will influence the decision on when to thin (Costa and Vizzotto 2000, Reighard and Byers 2009).

Regulating the number of flowers and bearing positions can be performed during the previous season. This can be achieved by spraying gibberellic acid (GA_3) during the flower initiation period in summer (Costa and Vizzotto 2000, González-Rossia et al. 2007, Reighard and Byers 2009). The GA application reduces flower numbers, therefore reducing fruit set and early competition between fruit. This would therefore reduce the amount of hand thinning required (González-Rossia et al.

2007, Reighard and Byers 2009). This method has not been widely accepted because of the uncertainty regarding fruit set due to early season frost or other unfavourable conditions for set (Costa and Vizzotto 2000). Chemicals e.g. ethephon, hydrogen cyanamide, dormant- or soybean-oil could be used during the dormant period, autumn and winter, to reduce the number of flower buds, but the results have been inconsistent (Costa and Vizzotto 2000, Reighard and Byers 2009).

The pruning of peaches is performed to maintain a balance between vegetative and reproductive growth, and to maintain the size and shape of the tree (Miller and Byers 2000, Marini 2003). It allows for better light distribution throughout the canopy and, the penetration and drying of sprays are improved (Marini 2003, Demirtas et al. 2010). Summer pruning before harvest is used to improve light distribution for colouration of fruit and delays the senescence of shoots and leaves (Flore 1992). Summer pruning also has an influence on fruit size and quality of fruiting wood, and thereby also improves fruit quality (Bester et al. 1994). Dormant pruning performed on peaches is a simple method of reducing the number of flowers before thinning (Marini 2003, Reighard and Byers 2009). This includes the removal of strong upright growing water shoots and any weak or short fruiting shoots, where unwanted fruit will set and the possibility for smaller fruit are greater, as well as regulating the number of fruiting shoots per tree (Bester et al. 1994, Reighard and Byers 2009). When fruiting one-year-old shoots in peaches were headed to remove up to 50% of the shoots, it resulted in the reduction of the initial crop load and cost of thinning, but it also had a negative effect on fruit size (Marini 2003). This is because the flower densities of peaches are higher at the basal end of the shoots. It is therefore recommended that entire shoots should be removed to reduce the initial crop load (Marini 2003). Marini (2003) reported that there was a positive correlation between the number of shoots on a peach tree, the fruit set and number of fruit that has to be removed with hand thinning (Marini 2003). Therefore, if more shoots are left on the tree, the harvest is delayed, the fruit weight and the crop value per tree is decreased (Marini 2003). Therefore to reduce the required time to hand thin, producers need to determine the number of fruit the cultivar can adequately size (Marini 2003). Using this, the number of bearing shoots per tree is determined, and through dormant pruning ca. ±3 weeks before bloom shoot number is adjusted accordingly (Bester 1994, Marini 2003). This early method of flower thinning ensures that the remaining buds will receive more reserves for rapid cell division during phase I of fruit growth, thus resulting in higher yields of larger fruit (Byers et al. 2003, Marini 2003). Any overlapping shoots or shoots that are too close to the ground needs to be removed, because they lead to chafe marks on the fruit (Bester 1994). In terms of pruning and hand thinning time, the difference between pruning trees with 73 and 220 shoots are ±4 min per tree. The time required to hand thin trees 40-60 dafb with 73 shoots and 220 shoots were 13 min and 63 min, respectively (Marini 2003). Hand thinning is not eliminated through pruning and is still required to adjust the final crop load (Byers et al. 2003, Reighard and Byers 2009).

Thinning can also be implemented during stage I of fruit growth or at bloom. During phase I of fruit growth cell division takes place, which means that thinning early during this time would stimulate cell division in the remaining fruitlets and increase the potential for bigger fruit sizes (Reighard and Byers 2009) compared to thinning at the end of phase II (Costa and Vizzotto 2000). Reighard and Byers (2009) found that thinning peaches at bloom resulted in a 10 – 30% increase in fruit size and yield, compared to thinning 40 – 50 days after full bloom. Other advantages include earlier maturing fruit, with better colour (Myers et al. 1993), sugar, firmness and storability for class I marketing (Rosa et al. 2008, Hehnen et al. 2011). It also overcomes alternate bearing (Reighard and Byers 2009) and could result in more shoot growth (Myers et al. 1993). Especially for early ripening cultivars with short growing seasons and high market prices, this practise is a viable option (Costa and Vizzotto 2000, Reighard and Byers 2009). A problem that hampers the use of flower thinning is early season frost, which can reduce the fruit numbers even further and result in a low crop load (Rosa et al. 2008). For this reason it is suggested that the basal, later opening flowers are kept intact, for assurance against frost. The advantages of flower thinning are thus still partially obtained and the use of follow-up hand thinning could be used to adjust the final crop load (Reighard and Byers 2009).

Hand thinning of fruitlets is normally performed towards the end of fruit growth stage II (pit hardening) or the beginning of stage III (Costa and Vizzotto 2000). This is after natural fruit drop is completed and only the excess, smaller, damaged or misshapen fruit will be thinned off (Costa and Vizzotto 2000, Southwick and Glozer 2000). The distribution of fruit along the shoots can also be determined to a better extent (Rosa et al. 2008). But the longer the thinning is delayed, the more negative the influence on the final size of the fruit remaining due to early competition for resources (Southwick and Glozer 2000). It will also result in a depletion of assimilates for the next season and thereby reduce the cropping potential (Costa and Vizzotto 2000).

Mechanical thinning

The history of mechanical thinning

Non-manual thinning methods are seen as part art and part science and the skill is therefore learned through trial and error (Reighard and Byers 2009). The search for an alternative to hand thinning has started as early as the 1950's, but neither chemical nor mechanical thinning has been widely implemented due to inconsistent and unsatisfactory results (Rosa et al. 2008). Sustainable fruit production is gaining in importance (Bertschinger et al. 1998). Consumers demand environmentally friendly products therefore producers need to optimize the ecological and economical flower and fruit thinning methods (Bertschinger et al. 1998). The need for more environmentally friendly growing methods (Damegrow and Blanke 2009), and limited and expensive labour, has opened the door for mechanical thinning (Baugher et al. 2008), but field results in 1981 illustrated that the expensive hand thinning still yielded better profit than mechanical thinning (Rosa et al. 2008). Mechanical thinning is therefore seen as new environmentally friendly technology (Solomakhin and Blanke 2010), which is also an alternative to chemical thinning (Damegrow and Blanke 2009, Hehnen et al. 2011)

As early as 1985, Byers and Lyons (1985) argued that money could be saved if a substitute for hand thinning could be found (Baugher et al. 1991). Preliminary studies with mechanical thinning at bloom were started by Baugher et al. (1988) and Byers (1989), but the techniques still needed refinement (Baugher et al. 1991, Byers 1989). They found two big disadvantages with early mechanical thinning machines: Firstly they removed more flowers from the upper canopy than the lower canopy of the tree, and secondly the mechanical thinning had to be repeated six times to achieve the desired thinning effect (Baugher et al. 1991, Byers 1989).

Mechanical thinning, however, is seen as an aid to hand thinning, rather than a replacement, with skilled labour being required in smaller numbers to adjust the final crop load (Wertheim 1997, Schupp et al. 2008, Damerow and Blanke 2009). To date none of the mechanical thinners tested (trunk shakers, low-frequency electrodynamic limb shaker, high pressure water streams and rotating curtains) have proven to have a high enough efficiency in peach trees to be able to completely replace hand thinning (Schupp et al. 2008). The cost of bloom thinning by hand or mechanical thinning plus hand thinning at fruitlet stage, should always be compared to only carefully removing fruitlets 40 to 60 dafb (Reighard and Byers 2009).

The advantages of mechanical thinning compared to chemical thinning are that the effect of thinning could be observed while thinning is performed. Therefore it could be said it is more reliable than chemical thinning, and could be an economic alternative to chemical thinning (Miller et al. 2011). In addition, chemical thinners for stone fruit are scarce and/or often ineffective, and are being phased out as fewer are still registered for use on stone fruit (Solomakhin and Blanke 2010, Seehuber et al. 2011). The declining use of chemicals is due to the fact that they are largely dependent on weather conditions, tree age and the flower dynamics of the tree (Solomakhin and Blanke 2010, Hehnen et al. 2011). Registration is also becoming increasingly difficult in many European countries (Hehnen et al.

2011). An advantage of mechanical thinners is that the thinning effect of a mechanical thinner is clear directly after the treatment, whereas the effect of chemical thinning will only be observed a couple of weeks later (Byers 1989, Baugher et al. 2009). This allows the producer to adjust the thinning severity while hand thinning, if needed, and portions of the tree could be selectively thinned, leaving parts with lower blossom density unthinned (Baugher et al. 2009). Another advantage is that mechanical thinners, when correctly used, distribute the fruit more evenly over the shoot (Rosa et al. 2008) and also leave flowers on parts of the shoots where the potential for forming larger fruit is higher in comparison to chemical thinners, which have the tendency to leave more flowers at the basal end of the shoots where the potential for bigger fruit is lower (Byers 1989).

The first machines

A number of mechanical thinning options have been evaluated over the past few years. These include labourers with rakes, trunk-shakers (Reighard and Byers 2009), low-frequency electrodynamic limb shakers (Rosa et al. 2008), high-pressure water streams (Byers et al. 2003, Reighard and Byers 2009), rope curtains (Baugher et al. 1991), rotating curtains (Baugher et al. 1991, Schupp et al. 2008), spike-drums (Glen et al. 1994, Baugher et al. 2008) and impact shakers (Schupp et al. 2008).

The use of a tree-width rope curtain dragged over the trees reduced the hand thinning time by 40% and increased the fruit weight by 10 to 20% (Baugher et al. 1991). The rope curtain was designed with 3 cm thick ropes, 3.7 m long and evenly spaced along a 6 m long supporting frame (Baugher et al. 1991). The technique removed more flowers from the upper canopy, than lower canopy, and the treatment needs to be repeated more than once to get a positive result (Baugher et al. 1991). The rotating curtain experienced the same problem (Baugher et al. 1991, 2009), but the treatment only had to be performed once (Baugher et al. 1991). The rotating curtain thinner has four quarter tree width curtains, 5.08 cm thick, four inches spaced ropes, suspended like curtains attached to a rotating arm on a tractor (Baugher et al. 1991). The rope curtain is significantly influenced by the tree shape. Pruning to remove overlapping shoots improved the thinning ability of the machine (Baugher et al. 1991, Reighard and Byers 2009). Hand thinning was reduced by 40 to 100%, but due to more flowers being left in the bottom half of the tree, hand thinning was still required (Baugher et al. 1991).

The use of rakes to knock off fruit at the normal thinning time (40-50 dafb) reduced the number of fruit on the tree, but did not address the problem of thinning being a labour intensive practise and damage to fruit was also reported (Rosa et al. 2008).

Thinning 40-60 dafb vs. bloom thinning allowed for more uniform distribution of fruit (Glenn et al. 1994, Rosa et al. 2008). The trunk shaker was effective on peaches trained to a V- or regular vase shaped trees, but a major problem was that it preferentially removed the bigger, higher quality fruit from the upper part of the canopy (Rosa et al. 2008).

Even though the trunk shaker increased fruit size in peaches, it tended to leave clusters of fruit (Rosa et al. 2008). Though the thinner improved fruit size due to removing excess fruit, the machine tended to remove larger rather than smaller fruit (Reighard and Byers 2009) and therefore the increase in fruit size was less than was achieved by hand bloom thinning (Glenn et al. 1994). The time needed for hand thinning was reduced by 57%, but there was also a 30% reduction in yield (Rosa et al. 2008). Other problems include the unpredictability in the removal of fruit because of variations in shaking intensity, limb stiffness and tree structure (Reighard and Byers 2009). Damage also occurred to the trees (Reighard and Byers 2009) including leaf drop (Rosa et al. 2008).

The spike drum was originally designed to harvest oranges (Schupp et al. 2008). The thinning of fruit by the machine was non-selective (Glenn et al. 1994). Thinning peach trees at the green fruit stage reduced the need for hand thinning by 50%, reduced the crop load by 58% and increased fruit size by 9% (Schupp et al. 2008). The removal of fruit was more on the horizontal than vertical shoots, and more fruit were removed from the outside of the canopy than the inside (Glenn et al. 1994). The reduction in crop load and overall distribution of fruit in the tree remains a limitation to its usefulness (Schupp et al. 2008).

BAUM

The BAUM (Bonner Ausdünnungsmashine) was developed at the University of Bonn to thin trees during bloom using centrifugal force (Solomakhin and Blanke 2010, Hehnen et al. 2011), and has a positive impact on fruit quality and alternate bearing (Damegrow and Blanke 2009, Hehnen et al. 2011). The device was originally developed for the thinning of apple trees, but the results showed that it could also be used to thin other fruit crops like pears, peaches, apricots, almonds and plums (Damegrow and Blanke 2009, Hehnen et al. 2011). The device is mounted on a tractor and is driven by the hydraulic system of the tractor (Damegrow and Blanke 2009). It consists of a 3 m vertical spindle with three horizontal rotors, which can be set independently of each other (Damegrow and Blanke 2009). The device can therefore be used with different tree architectures and planting densities (Solomakhin and Blanke 2010, Hehnen et al. 2011). On four sides of each rotor, plastic chords are attached that act as whips when passing through the tree (Damegrow and Blanke 2009). The brushes removed up to a third of the flowers on the shoots, when trees were trained to a slender spindle (Damegrow and Blanke 2009, Seehuber et al. 2011). The number of flowers removed can precisely be determined by choosing between a selection of brush types, rotor speeds, rotor positions and tractor speeds (Damegrow and Blanke 2009). Optimal thinning was achieved in apple trees at a rotor speed between 300 to 420 r.p.m., with a tractor speed of 5 to 7 km h^{-1} (Damegrow and Blanke 2009). Hehnen et al. (2011) reported that a rotor speed of 260 or 360 r.p.m., with a tractor speed of 2.5km h^{-1} had the best effect on seven-year-old 'Buckeye Gala' apple trees (Hehnen et al. 2011). The thinning had a positive impact on fruit size (Damegrow and Blanke 2009, Hehnen et al. 2011), fruit firmness, it advanced maturity, improved the colour of the fruit (Solomakhin and Blanke 2010, Hehnen et al. 2011) and eliminated alternate bearing (Damegrow and Blanke 2009, Solomakhin and Blanke 2010, Hehnen et al. 2011). This led to a 60 to 80% increase in class I pack-out in 'Elstar', 'Braeburn', 'Royal Gala' and 'Golden Delicious' apple trees (Damegrow and Blanke 2009). While there was an increase in fruit size, the cost of labour (Damegrow and Blanke 2009, Hehnen et al. 2011) and the usage of chemical thinners was also reduced (Solomakhin and Blanke 2010, Hehnen et al. 2011). Seehuber et al. (2011) performed trials on 'Ortenauer' European plum and used a rotor speed of 400 r.p.m. and removed 50% of flowers to obtain a fruit to flower ratio of 5:1. In the trials performed on European plums, the fruit size was also increased from 28 to 32 g, the overall fruit quality was increased and alternate bearing was overcome (Seehuber et al. 2011). The BAUM reduced the number of fruit in the tree periphery, but also in the area close to the trunk where fruit of lesser quality develop (Damegrow and Blanke 2009).

The BAUM reduced production cost by reducing labour input. The time needed to thin was reduced by between 15 to 30 h ha^{-1} (Damegrow and Blanke 2009) or 48% (Hehnen et al. 2011). A reduction in yield was reported by Hehnen et al. (2011), but the higher value fruit with better quality out-weighed the decrease in yield. Solomakhin and Blanke (2010) also found fruit size improved by 16 and 14% for 'Mondial Gala' and 'Golden Delicious Reinders', respectively, at a tractor speed of 7.5 km h^{-1} and a rotor speed of 360 r.p.m. (Solomakhin and Blanke 2010).

Damegrow and Blanke (2009) found less than 8% damage to leaves and branches while Solomakhin and Blanke (2010) found an increase in damage with increasing rotor speed and a decrease in tractor speed, which also increased the number of flowers thinned. With the lowering of the tractor speed, the trees with longer branches were damaged more than those with short branches, because the longer branches showed more resistance to the rotors (Solomakhin and Blanke 2010). Not many flower clusters or spurs were completely removed when the BAUM was used in an apple orchard for the first time (Damegrow and Blanke 2009). The fruit set after "June drop" declined as the thinning intensity was increased. The fruit set was reduced to between 58 and 66% for the machine treatments compared to 93% for the un-thinned control for 'Royal Gala' and 'Golden Delicious' apples (Solomakhin and Blanke 2010).

Darwin

The original Darwin was called a wire-machine and was designed by H. Gesseler in Friedrichshafen-Hirschblatt, Germany (Bertschinger et al. 1998). It was originally designed for the bloom thinning of narrow conical shaped organic apple orchards (Baugher et al. 2010a). The wire-machine was powered by the engine of any standard tractor and there was a vertical turning axil with nylon wires (40 cm length) secured to it (Bertschinger et al. 1998). Thinning was performed at 4 km h^{-1} and the rotor speed was set at approximately 1500 r.p.m. (Bertschinger et al. 1998). The original Darwin was further developed by Fruit Tec in Deggenhausertal, Germany, for bloom thinning of pyramid-shaped apple trees (Baugher et al. 2010a, Schupp and Baugher 2011). The devise is mounted on a tractor with a 3-point hitch, fork mount or a bolt-on mount (Baugher et al, 2009) and has a 3 m vertical spindle (Schupp et al. 2008, Baugher et al. 2010a, Schupp and Baugher 2011). The spindle can be tilted 30° in either direction from the centre (Schupp et al. 2008, Baugher et al. 2010a, Schupp and Baugher 2011). Attached to the spindle are a total of 36 steel plates which secure 648 plastic cords (Schupp et al. 2008, Ngugi et al. 2009), measuring 50 cm each (Schupp et al. 2008, Baugher et al. 2010a). The spindle is driven by the hydraulic system of the tractor and can be regulated by adjustments to the control valve, which is situated on the tractor (Schupp et al. 2008, Baugher et al. 2010a, Schupp and Baugher 2011). Intensity of thinning can be adjusted by changing the rotational speed of the spindle (Schupp et al. 2008, Baugher et al. 2010a, Schupp and Baugher 2011), the speed of the tractor (Schupp et al. 2008, Baugher et al. 2009, Schupp and Baugher 2011), or the arrangement of the plastic chords (Schupp and Baugher 2011). In seasons that higher fruit set is expected, the spindle speed needs to be increased to get satisfactory results (Kon et al. 2013). In order to conform to different tree shapes, the Darwin is produced with different spindle heights of 2, 2.5 and 3 m, and spindle angle can be changed (Baugher et al. 2009). The rotor speed can be adjusted between 150 and 400 r.p.m. (Baugher et al. 2009). Keeping the spindle parallel to the vertical plane of the tree canopy (Schupp et al. 2008), 10 cm away from the trunk (Aasted et al.

2011), will ensure a consistent thinning effect in the upper and lower canopy (Schupp et al. 2008). To achieve optimal thinning in consecutive years, the spindle position needs to be consistent. The removal of entire flower clusters in pome fruit has been described as an occasionally occurrence, and more often seen in the first season of using the Darwin in an orchard (Kon et al. 2013). Modifications to the Darwin were made with new prototypes being able to rotate the spindle horizontally (Baugher et al. 2009, Reighard and Henderson 2011, Schupp and Baugher 2011), which is especially useful in open vase shaped training systems (Baugher et al. 2009, Reighard and Henderson 2011, Schupp and Baugher 2011).

Kon et al. (2013) evaluated the influence of the number of chords attached to the Darwin 250™ spindle on thinning severity at bloom in apples. The tractor speed was set at 4.8 km h^{-1} and the rotor speed at 240 r.p.m.. The three treatments were 90, 180 and 270. Results showed that when the number of chords increased, the contact with the canopy, the thinning severity and so too the damage to reproductive and vegetative structures increased. When 180 chords were selected, a significant increase in fruit weight was found, but the increase in mean fruit weight over all the different treatments was less than 4 g (Kon et al. 2013).

The effect of increasing the spindle speed while the number of chords (90) on the spindle and the tractor speed (4.8 km h^{-1}) were kept constant was also evaluated by Kon et al. (2013). The 'Buckeye Gala' trees, trained to a slender spindle, narrow fruiting wall, were thinned using spindle rates of 180, 210, 240, 270 and 300 r.p.m. (Kon et al. 2013). Increasing spindle speed increased the number of flower clusters removed while fruiting wood was removed from two and three-year-old wood, which encouraged the development of fruit on the periphery of the canopy (Kon et al. 2013). These lateral buds on the two and three-year-old wood remain after thinning and is the area where inferior fruit develop (Kon et al. 2013). The expected increase in fruit size and quality were not found while the increase in spindle speed also resulted in damage to the bark, shoots and buds (Kon et al. 2013). The yield was decreased by up to 50% with the highest spindle speed, which could have been acceptable if the fruit size was increased (Kon et al. 2013). There was also no relationship between the bloom thinning with the Darwin 250™ and return bloom (Kon et al. 2013).

Baugher et al. (2010a) thinned 'Sugar Giant' peach and 'Arctic Sweet' nectarine trees at different times during bloom from the pink stage to petal fall at a constant tractor speed of 4.0 km h^{-1} and a spindle speed of 150 r.p.m. At pink stage the thinning intensity needed to be increased to remove the same number of flowers as at later stages of bloom thinning (Baugher et al. 2010a). Schupp et al. (2008) thinned Artic Sweet nectarine and White lady and Babygold 5 peaches at 80% full bloom while 'Redhaven' peach was thinned at 20 and 80% full bloom. Blossom removal for the four cultivars was between 30 to 46%, and there were no significant differences between cultivars, canopy position and bloom stages (Schupp et al. 2008). Baugher et al. (2010a) found that thinning at different stages during bloom reduced the time required for follow-up hand thinning compared to a control (thinned only at 40 – 60 dafb). The reduction was 51% for bloom thinning performed at 20% full bloom in 2008 and 41% for thinning at petal fall in 2009 for 'Sugar Giant' peach. For 'Artic Sweet' nectarine, bloom thinning performed at 80% full bloom resulted in a 42 and 22% reduction in two years, respectively (Baugher et al. 2010a). The economic results are the same for different stages of bloom thinning and therefore the positive effect is gained through an increase in fruit size and economic value, and the decrease in requirement for hand thinning (Baugher et al. 2010a). Producers will therefore have an extended period for bloom thinning (26 days), and can therefore thin as late as possible, if they are concerned about freezing temperatures (Baugher et al. 2010a). This could also help with the distribution of labour-intensive work over a season (Baugher et al. 2010a).

'Redhaven' peaches showed a 24% reduction in labour cost when blossom thinning was performed at 20% full bloom, and 42% when it was performed at 80% full bloom (Schupp et al. 2008). The reduction in the time required for follow-up hand thinning was also similar to the reduction in crop load (Baugher et al. 2010a). Schupp et al. (2008) found in 'Redhaven' peach that there was a reduction in crop load when bloom thinning was performed at 80% full bloom, but not at 20% full bloom. This agrees with Baugher et al. (2010) who found that the thinning intensity needs to be increased when thinning is performed at pink blossom stage to achieve the same percentage removal of blossoms as when thinning at later stages of bloom (Baugher et al. 2010a). The percentage of fruit in the 7 cm and greater size category was increased by all the bloom treatments for both cultivars (Baugher et al. 2010a). There was no significant difference in mean fruit size at harvest between the trees thinned at 20 and 80% full bloom in 'Redhaven' peaches and also did not differ from the trees only hand thinned at 40 to 60 days after full bloom (Schupp et al. 2008). There was, however, an increase in the percentage of large, high market value peaches, with the trees thinned at 20% full bloom (Schupp et al. 2008). The increases in fruit size and the decrease in hand thinning time required, increases the value of the two cultivars far beyond that of hand thinning at fruitlet stage alone (Schupp et al. 2008, Baugher et al. 2010a).

A Darwin prototype was developed to thin open vase trees with more complex tree structures (Baugher et al. 2009). The spindle was shortened to 2 m and 144 chords attached (Baugher et al. 2009). The spindle can tilt 30° downwards or upwards to thin the sides and tops of the tree (Baugher et al. 2009, Baugher et al. 2010). Baugher et al. (2009) set the tractor speed at 4 and 2 km

h^{-1} and a spindle speed of 200 r.p.m. The trials were performed on five peaches, viz. 'Snow Giant', 'Loring', 'Cresthaven', 'John Boy' and 'Harrow Diamond', at 80 and 60% full bloom, and at pink stage on the early maturing cultivar Rising Star (Baugher et al. 2009). With the tractor speed at 4 km h^{-1} the hand thinning time required was reduced by 5 to 34% in the lower canopy and 23 to 51% in the upper canopy (Baugher et al. 2009). When the tractor speed was reduced to 2 km h^{-1} the hand thinning time required was reduced even more, ranging from 33 to 51% in the lower canopy and 48 to 69% in the upper canopy (Baugher et al. 2009). The same results were achieved, as with the conventional Darwin, where the fruit diameter and percentage of fruit in the high-market-value categories was increased (Baugher et al. 2009). Reighard and Henderson (2011) thinned two peach cultivars, Coronet-N and Clemson Lady, trained to an open centre canopy and using the Darwin 250™ prototype thinner at petal fall (full bloom plus three days) with a tractor speed set at 3.2 km h^{-1} and a spindle speed at 225 r.p.m.. Trees were thinned by passing the tree on four sides, i.e. the two sides and twice over the top of the tree or an aggressive thinning only from the top of the canopy, with two passes over the top of the tree. With the four passes, the number of blossoms was reduced by 55% in the upper and outer scaffolds and 37% in the inner scaffolds while in the more aggressive approach it was reduced by 62 and 64% for the outer and inner scaffolds, respectively. Both the treatments under thinned because not enough flowers were removed from the lower parts of the canopy. In terms of reducing labour costs, increasing fruit size and gross crop value, the more aggressive approach performed better and the higher gross value was mostly due to larger fruit (Reighard and Henderson 2011). Baugher et al. (2010) performed trials on two canning peach cultivars, Toulumne and Loadel, with the hybrid Darwin 250™ (Baugher et al. 2010b). The hollow, moulded cords used were 50.8 cm long, whereas previously coiled plastic cords were used (Baugher et al. 2010b). The cultivars were trained to a perpendicular V system and thinning was performed on both sides of the canopy and the top (Baugher et al. 2010b). There was a high removal of blossoms that resulted in a reduction of 19 to 40% of the hand thinning required. The fruit size was increased, along with the size distribution and the market value of the fruit thereby increasing the economic value of the canning peaches beyond that of hand thinning alone (Baugher et al. 2010b). This increase is due to the savings in labour cost and the increases in yield with improved fruit size (Baugher et al. 2010b).

The spread of pathogens can be a problem when using the Darwin (Bertschinger et al. 1998, Ngugi, et al. 2009). Bertschinger et al. (1998) reported that the Darwin could help spread pathogens like *Erwinia amylophora* (causal agent of Fireblight) or *Nectria gallingea* (Canker) in apples (Bertschinger et al. 1998) and increase the aphid population. The chords not only slice away the flowers, but also made fresh wounds on the primary spur leaves and cambium tissue of apples (Ngugi et al. 2009, Kon et al,. 2013). These wounds would be the same as after a hail or storm event thus, when this combines with the right temperature and moisture for pathogen growth, the presence of an inoculum, a susceptible host (tree with cut wounds) and a vector (Darwin), the spread of pathogens could be enhanced (Ngugi et al. 2009). This was observed in apple trees where the non-inoculated trees were infected after the machine past through trees inoculated with fireblight (Ngugi et al. 2009). The thinned trees also had twice as many shoots infected as the non-thinned trees (Ngugi et al. 2009). Care must therefore be taken before thinning to take environmental aspects into consideration (Ngugi et al. 2009). If the orchard has had any disease previously, the machine should not be used, and in the case of fire blight outbreak, it should be treated by the use of a bactericide (Ngugi et al. 2009).

A problem with the current Darwin is that the driver of the tractor has to weave in and out of the trees to maintain the engagement with the tree to achieve an evenly distributed thinned orchard (Aasted et al. 2011). This is physically and mentally tiring to the operator of the tractor and Aasted et al. (2011) have evaluated two systems to address this problem. The first is where the operator drives the tractor in a straight line and controls the movement of the spindle by means of a joystick, which would not address the problem at hand. The other solution is to make use of lasers to control the spindle while the tractor is driven in a straight line. The laser system is mounted on front of the tractor while the spindle is mounted on the back. The laser scans the tree and places the spindle 10 cm away from the tree where the cords would be able to engage the tree. The laser has a fine balance between engagement and hitting an obstacle. The penalty for hitting an obstacle is bigger than not thinning a part of the tree correctly. The laser system had the same outcome as the joystick, although it under thinned the lower part of the canopy. Both the systems over thinned because of the lower tractor speed and higher spindle speed used (Aasted et al. 2011).

The influence of training systems on thinning

According to Damegrow and Blanke (2009) mechanical thinning could be an alternative to chemical thinning if the trees are trained to narrower canopies. Open-centre trees are difficult to thin because of the complexity of the training system (Baugher et al. 2009) compared to narrow canopy widths, which are more uniform in geometry (Bertshinger et al. 1998, Schupp et al. 2008, Reighard and Henderson 2011). Therefore it is suggested that training systems need to be modified to optimise for automation (Schupp et al. 2008, Baugher et al. 2009).

Open centre canopies have a more variable flower removal percentage than V-systems because of the difference in tree structure, canopy depth and pruning strategies (Schupp et al. 2008, Baugher et al. 2009). Even if trees are trained to a narrow canopy, the thinning effect ranged between 2 to 28% for interior and 41 to 65% for the exterior, depending on the cultivar and bloom stage (Schupp et al. 2008). If the tree has big open spaces in the canopy, the spindle will navigate into it and over thinning will occur (Baugher et al. 2009). Pruning trees to shorter permanent branches and reducing the one-year-old growth are needed (Schupp et al. 2008). Branches longer than 70 cm and a pyramidal training system had a negative effect on the thinning success. Blossom removal from shoots that are parallel to, or extend into the work row is much more effective than from the interior branches (Schupp et al. 2008). These interior branches are the location of lower quality fruit (Bertschinger et al. 1998). A canopy with a lot of overlapping branches will stop the spindle from reaching all the branches and under thinning will occur (Baugher et al. 2009). Canopies with a lot of depth will be ineffectively thinned in the lower parts of the canopy and take longer to thin than the V-systems (Baugher et al. 2009). Open centre trees are more complex structure and the spindle has to be frequently adjusted to keep the spindle in close proximity to the limbs, without striking the limbs (Baugher et al. 2009). The more complex the tree structure the slower the tractor speed needs to be to allow the driver time to adjust the spindle (Baugher et al. 2009).

Schupp and Baugher (2011) performed trials on V- and open-centred peach trees to experiment with different pruning strategies. These modifications in pruning strategies entailed the alteration in shoot orientation, pruning detail and/or the scaffold accessibility to assist thinning with the Darwin. Thinning with the Darwin was performed between 20 and 80% full bloom, at a tractor speed of 4 km h^{-1} and the spindle speed was set at 180 and 150 r.p.m.. The pruning strategies made the blossom removal by mechanical thinning more consistent; this included the removal of excessively long or short branches (>45cm, <15cm) thereby increasing the canopy accessibility. Shoots in less accessible areas of the canopy also needs to be removed, and the training of trees would need to attain a narrow tree wall system. The follow-up hand thinning time required was reduced with detailed pruning compared to the green fruit removal only and standard pruning. The hand thinning time required was reduced by 46% in V-shaped ‘John Boy’ trees and 22 and 47% in open-centred ‘Loring’ and ‘PF20-007’. The hand thinning time ranged from 42 to 66, 24 to 28 and 10 to 15 h ha^{-1}, for ‘John Boy’, ‘Loring’ and ‘PF20-007’, respectively, compared to the control of 78.3, 30.7 and 19.3 h ha^{-1}. The fruit size was increased by the pruning strategies and the percentage of fruit in higher market value size was increased by detailed pruning in all the trial except in ‘Loring’ (open-centred). The time savings in hand thinning and increases in fruit size following corrective pruning resulted in an increase in crop value far beyond that of hand thinning alone. The time required for pruning could also be decreased because shoots growing in a certain direction needs to be removed, whereas with standard pruning judgement is required to choose the shoots with highest potential (Schupp and Baugher 2011).

Chemical thinners

Introduction

Interest in chemical bloom thinning has increased recently due to hand thinning not being cost effective (Baugher et al. 2008). Chemical thinning options for stone fruit are limited (Schupp et al. 2008) and chemical thinners considered include caustic materials, growth regulators and photosynthetic inhibitors (Southwick et al. 2008, González-Rossia et al. 2007). In apple growing effective chemical thinners are available, but the search continues for an effective stone fruit chemical thinner. The primary advantages of an effective chemical thinner include that it is quick, easy and relatively inexpensive to use (González-Rossia et al. 2007). Chemical thinning can be performed at bloom or shortly thereafter to reduce current season crop load (Wertheim 1997) or during the flower induction phase to reduce flower density and therefore crop load the following season (Southwick et al,. 1995).

Registered thinning chemicals in pome fruit have become fewer (Damegrow and Blanke 2009). This is due to various reasons, e.g. carbaryl is harmful to a wide spectrum of insects and water organisms (Wertheim 1997), naphthyl acetic acid (NAA) is being phased out in many European countries (Damegrow and Blanke 2009), and the renewal costs of registration is high and exceeds the return (Wertheim 1997). In addition, the efficacy of the few available chemicals is temperature dependent (Damegrow and Blanke 2009). Other disadvantages include that the chemical thinners give inconsistent results (Baugher et al. 2009) due to variable responses to weather conditions, flower dynamics and tree age (Hehnena et al. 2011). In addition, the response to chemical thinners is not immediately visible as unfertilized fruit will still persist on the tree until 35-60 dafb (Byers 1989). The remaining chemical thinners available in Europe include lime sulphur, ammoniumthiosulfate (ATS), ethephon (Ethrel (Bayer), Flordimex (Nufarm)) and 6-benzyladenine (6-BA, Maxcel (Valent), Globaryl (Globachem) or Exilis (Fine)) (Damegrow and Blanke 2009).

In the following section we will review the literature on chemical thinning only as far as reducing reproductive bud initiation and therefore flower density and crop load the following season.

Gibberellin as a chemical thinner

Gibberellin and mechanism of action

The discovery of gibberellin (GA) can be traced back to the 1920s when a Japanese pathologist studied foolish disease in rice (Greene 2010). This disease causes rice plants to grow rapidly, therefore developing weak stems that results in lodging (Greene 2010). The rapid growth was caused by a growth stimulant produced by the fungus *Gibberellia fujikuroi.* In the 1950s, gibberellic acid (GA_3) was identified, crystallized and synthesized (Greene 2010).

GA is applied to trees to reduce flower induction while it also improves fruit quality and could delay harvest and improve the storability of the fruit. GA applied at stage III of fruit growth has resulted in firmer and heavier fruit. It also delays maturity and fruit softening, which could be of great value for late ripening cultivars, but not for the early maturing cultivars (Lurie 2010). Application of GA at the right time and rate decreases the differentiation of flower buds (Southwick and Glozer 2000).

By applying foliar GA_3 to peach trees, Jourdain and Clanet (1987) established that the flower induction period is between October and late January (Southern Hemisphere) (González-Rossia et al. 2007). It was further narrowed down to between late November and mid-January with a peak in mid-December (late May, through to July for Southern hemisphere), but differs between cultivars (Southwick and Glozer 2000, Reighard and Byers 2011). The number of flower buds that eventually form on the tree is dependent on the crop load of the previous year (González-Rossia et al. 2006 2007), and the health and the quality of fruiting wood of the tree (Reighard and Byers 2011). Bloom thinning or loss of crop load due to frost will have a positive effect on shoot growth or flower differentiation in stone fruit. Up to 50% more bearing shoots and 50% more flower buds are formed if trees are bloom-thinned rather than hand thinned at 40 - 50 dafb. Therefore a non-cropped tree will have more shoot growth and flower buds than a bloom thinned tree. The biggest increase in flower buds is near the base of shoots of the current season. These buds will also open later in spring, thus also giving security against late season frost (Reighard and Byers 2011).

Winter chilling is important for flower buds to be released from dormancy. If a flower bud receives sufficient chilling, it will develop normally if the temperatures start to increase in spring. However, if the flower bud does not receive enough chilling, its development will be retarded. The flowering period could also be extended and an increase in flower bud abortion could also be expected. Trees with a high chilling requirement will not flower or will produce inadequate fruit if the trees did not receive enough chilling (Reighard and Byers 2011).

The differentiation of buds along a shoot and between different lengths of shoots differs. It was also seen that it differed between early, mid and late ripening cultivars. When GA was applied to a shoot where the basal buds where already initiated before the application was made, the buds were delayed in their development (Southwick and Glozer 2000). These authors noted that short shoots entered the floral induction period earlier than long shoots. The induction progressed acropetally on both lengths of shoots. Furthermore they suggest that while the different length of shoots has different times of differentiation, the buds on a shoot will end differentiation at the same time. Byers et al. (1990) also found that short shoots differentiate their flower buds earlier, or stop growing earlier, than long shoots, since the increase in buds per terminal was greater on short shoots compared to long shoots the year following hand thinning during the bud differentiation period. Bud differentiation begins four buds back from the shoot apex on growing peach shoots (Southwick and Glozer 2000).

Any change in the competitive allocation of resources during the differentiation period will have an influence on the differentiation of the buds. These are changes like fruit thinning during the differentiation period. There are several factors such as light, climate, the irrigation regime, nutrient status, rootstock, pruning and geographical location that influence shoot growth at the time of floral initiation and bud formation (Southwick and Glozer 2000). Consequently, it may be difficult to find the appropriate GA concentration and application times too adequately reduce the number of flowers and these may also vary from season to season and among cultivars.

GA produced by developing apple fruit 3-8 weeks after full bloom causes alternate bearing (González-Rossia et al. 2007). Ebert and Bangerth (1981) found that the GA production peaks nine weeks after full bloom, although the production of GA already started 2-3 weeks after full bloom (González-Rossia et al. 2007). When GA is produced by the seeds of fruit (González-Rossia et al. 2007), it moves to the nearby nodes and inhibits the initiation of new floral primordial (González-Rossia et al. 2006). Therefore, if GA is applied during the induction period, the number of flower buds for the next growing season could be decreased (González-Rossia et al. 2006, 2007). GA_3 is commercially used in citrus, avocado, apricot, mango, pome fruits and peaches to reduce the number of flowers and thereby the number of fruitlets that develop and the time required for hand thinning in the next growing season (González-Rossia et al,. 2006 2007). GA is environmentally friendly and no phytotoxic effects have been seen with rates between 47 and 97 g ha^{-1}, which enhances its potential as a chemical thinning agent (Southwick and Glozer 2000).

The mechanism through which GA_3 inhibits floral bud induction is not known, but in apples it is believed that the source strength of vegetative growth is increased, thereby increasing the usage of carbohydrates (Lenahan et al. 2006). Bangerth (2000) stated that the application of GA_4 (100 ppm) on 'Starking Delicious' apple, under low light conditions decreased the drop of shaded fruit by up to 95%. The mechanism by which the GA_4 decreased the drop could be because the application of GA_4 stimulated the export of IAA, rather than affected the availability of carbohydrates under low light conditions (Bangerth 2000). The fruit and/or bud would hereby stay dominant over the lateral buds (Bangerth 2000). This is also seen in an increase in the internode length of shoots (González-Rossia et al. 2007). This could result in the beginning of an alternative bearing cycle (Lenahan et al. 2006, González-Rossia et al. 2007). However, the application of GA_3 could also have a positive effect on alternate bearing where the competition for assimilates is reduced early in the growing season (Southwick et al. 1995). The endogenous production of GA in trees promotes growth, therefore if the synthesis of GA is reduced, it would retard the growth of the tree, which could be useful when trees are vigorous, reducing the competition for nutrients between shoots and fruit (Lurie 2010).

Effect of Gibberellin on return bloom

In frost free areas, GA could serve as a reliable method of chemical thinning to reduce the flowering density on trees, and thus also potentially reduce hand thinning (Southwick et al. 1995). The reliability of GA as a chemical thinner is enhanced by the fact that the fruit set is unaffected for a wide range of flower bud production (González-Rossia et al. 2006). However, it is critical to apply GA in the induction period of the buds and not during differentiation period (Southwick et al. 1995). Byers (1989) found "early season" application (47 dafb) interesting in peach for three reasons. Firstly it reduced flower buds without the chance of overdose inhibition, secondly it inhibited the formation of basal flowers in bloom thinned trees and thirdly it reduced the number of flowers on short shoots. The application of GA 6-8 weeks before the cessation of shoot growth was still effective (Southwick and Glozer 2000). The optimum time for the application of GA_3 however is dependent on the cultivar and the current crop load (Byers 1989). An application in early autumn (March in the Southern hemisphere) reduced the number of flower buds by causing bud abortion/death while application in April delayed bloom (Southwick and Glozer 2000). Too many flower buds were killed with summer or autumn applications and the Environmental Protection Agency in Europe did not clear the use of the product (Hehnen et al. 2011).

The sensitivity of a cultivar is time- and cultivar specific, and is dependent on the meristematic activity at the time or sensitivity in floral buds (Southwick and Glozer 2000, Lenahan et al. 2006).

González-Rossia et al. (2006) suggested that Japanese plum 'Black Gold' is more sensitive to GA_3-application than 'Black Diamond' and that the effect of the GA_3 application is depended on the rate applied and the type of shoot. Taylor and Geisler-Taylor (1998) found that the flower inhibition on long and short shoots in peach is dependent on the application, concentration and the cultivar (González-Rossia et al. 2006). The time of flower induction is the same for peaches and nectarines and the effectiveness of the treatment is dependent on the total amount of active material applied to the trees, not the concentration (González-Rossia et al. 2007). In peaches 50% reduction of flower buds was attained with 50 mg L^{-1} GA_3 per tree, whereas in nectarine trees 100 mg L^{-1} per tree was sufficient (González-Rossia et al. 2007). The effect that occurs on the tree is also dependent on the part of the shoot sprayed with the GA having a bigger effect on the basal part of the shoots. The reduction was also less in the apical region of the tree (González-Rossia et al. 2007). González-Rossia et al. (2006) found that long shoots of Japanese plum, had a higher sensitivity to GA_3 than spurs. This was thought to be because of the higher vigour of long shoots, and that younger trees and less vigorous mature trees are more sensitive to GA_3 sprays (González-Rossia et al. 2006). As such, mature trees would be more suited for GA_3 thinning (Southwick and Glozer 2000).

The application of GA in November through to January (SH) reduced the number of flowers in the next growing season without reducing fruit set (proportion of flowers setting fruit) (Southwick and Glozer 2000). This will therefore reduce the need for hand thinning of fruitlets and enhance the production of high quality fruit (Southwick and Glozer 2000). Lenahan et al. (2006) indicated that the flower density was linearly decreased by an application of GA_3 (100 and 200 mg .L^{-1}) during stage I and II of fruit growth in cherries, with the number of reproductive buds per spur reduced, and not the number of flowers per bud. The 30 - 100 mg L^{-1} GA_3 had no effect on fruit set in 'Bing' cherries (Lenahan et al. 2006), but there are still risks involved in the use of GA reducing the number of flowers, as under adverse climatic conditions during bloom, the fruit set and yield per tree could be decreased significantly (Southwick and Glozer 2000). However, the risk could possibly be out-weighted by the reduction in labour costs and the advantage of fruit of higher marketable quality (Southwick and Glozer 2000).

The timing of application is highlighted by Coetzee and Theron (1999) who found that the application of GA_{4+7} four weeks before harvest on 'Sunlite' nectarine reduced the number of reproductive buds significantly more than an application at harvest. No concentration effect of GA_{4+7} application was observed over the 90 to 180 mg L^{-1} range. The application four weeks before harvest only reduced the number of buds on the basal part of the shoots since the buds on the apical part of the shoot had not yet developed at the time. This effect is negative because the distal flowers are normally removed with blossom thinning. With a double application of 90 mg L^{-1} four weeks before harvest and at harvest, a bigger effect was found on long shoots than on short shoots. This is because the long shoots grow for a longer period than the short shoots, thereby growing between the two applications and being affected by both applications. The vegetative bud density was increased by an application of GA_{4+7} compared to the control and were not affected by the time of application or concentration. The reduction in the number of reproductive buds resulted in a decrease in the time required to hand thin. Hand thinning would still be required to space fruit evenly on shoots (Coetzee and Theron 1999), but growers could increase the number of fruits on the tree and clusters of two or three fruit could be left, because with the "earlier" thinning, the remaining fruit would develop to the required size (Southwick and Glozer 2000).

GA_3 reduced the return bloom more than GA_{4+7} and also delayed the harvest more when sprayed at 50 and or 100 mg .L^{-1} during flower initiation and before leaf fall on cherries (Lenahan et al. 2006). Lenahan et al. (2006) found that GA_3 and GA_{4+7} delayed bloom by 4-5 days when sprayed at 200 mg .L^{-1} on cherries. When 100 mg .L^{-1} was used, the GA_3 and GA_{4+7} reduced the flower density by 65%, but with 200 mg .L^{-1}, the GA_3 reduced the flower density by 92% and the GA_{4+7} only by 68% (Lenahan et al. 2006). The fruit set was not affected by the applications (Lenahan et al. 2006), but in apples the inverse was seen where the GA_{4+7} has a bigger effect than the GA_3 (Wertheim 1997, Lenahan et al. 2006).

Southwick and Glozer (2000) found that GA is effective from 10 to 1000 mg L^{-1}, but it is registered for use at 125 mg L^{-1} for use on peaches. With an increase in the concentration from 50 to 120 mg L^{-1}, the flower buds were linearly reduced in 'Loadel' cling peaches (Southwick and Glozer 2000). García-Pallas et al. (2001) also saw a linear reduction in the number of flowers per shoot length when applying 50, 100, 200 and 400 mg L^{-1} after harvest on 'Crimson Gold' nectarine. The flowering was only slightly delayed by the GA_3 applications and the flowers more elongated in shape (García-Pallas et al. 2001). This was also confirmed by Lenahan et al. (2006) and Lurie (2010) who found that a concentration of between 10 and 100 mg L^{-1} decreased the number of flower buds for the next growing season by 21 to 54% in cherries. The concentration used, without over thinning, was between 50 en 75mg L^{-1} and it satisfied the objective to lower the flowering by 50% (Southwick and Glozer 2000). 50 mg L^{-1} GA_3 was also recommended by González-Rossia et al. (2006), on the Japanese plums 'Black Gold' and 'Black Diamond', reducing the number of flowers by 31 to 43% and resulting in a 45 and 47% decrease in the time required for hand thinning for the 'Black Diamond' and 'Black Gold', respectively.

The applications of 50 mg L^{-1} GA over consecutive seasons to 'Patterson' apricots reduced the flowering by 50% in both seasons (Southwick and Glozer 2000). In a year when there were fewer flowers, the application of 50 mg L^{-1} GA did not reduce the flower numbers compared to the controls (Southwick and Glozer 2000). On the nectarine 'Crimson Gold', García-Pallas et al. (2001) reduced the number of flowers in two consecutive years with applications applied after harvest. An interesting finding by Southwick and Glozer (2000) was that when flower buds are reduced in the previous growing season, the remaining flowers will have higher cold hardiness and the set percentage will be higher under adverse conditions.

Effect of Gibberellin on current season fruit quality and harvest

Lurie (2010) reported that GA could be applied in stone fruit for a variety of reasons. This is, as noted above, to reduce the number of flowers and to have an influence on fruit quality, delay harvest and improve storability. She reported that applications of GA_3 to cherries increased the fruit firmness, decreased fruit softening and delayed fruit maturity for late ripening cultivars (Lurie 2010). The delayed maturity was not found for early ripening cultivars. This was also found by Lenahan et al. (2006), where the fruit maturity was delayed by GA_3 application of 50 and 100 mg .L^{-1} in cherries. In other studies on cherries, increases in fruit weight and sensory quality were reported, with a decrease in fruit cracking, pitting during storage and the sensitivity of fruit to bruising. GA_3 at a concentration of 50 or 100 mg .L^{-1} increased the TSS of cherries by 7 or 12% while fruit firmness increased by 15 or 20%, and the fruit weight by 7 or 1% (Lenahan et al. 2006). For Japanese plum, the cell enlargement of the fruit is increased when GA_3 is applied in the induction period, along with the acceleration of fruit development, and therefore the harvest date would be earlier (González-Rossia et al. 2007). In peaches and nectarines the application of GA_3 improved the fruit colour, increased TSS and fruit firmness (González-Rossia et al. 2007). The increase in fruit firmness could be correlated to an increase in the number of cells in the fruit tissue (González-Rossia et al. 2007). 50 mg L^{-1} GA_3 applied to 'Queen Giant' peach reduced the internal breakdown and bleeding (Lurie 2010). Coetzee and Theron (1999) applied 90, 120, 150 and 180 mg L^{-1} Ralex® (GA_3) at four weeks before harvest on 'Sunlite' nectarine. Results suggested that the fruit firmness was increased by the GA_3, but no concentration effect was found. The TSS was lower at harvest indicating a delay in ripening (Coetzee and Theron 1999). This delayed ripening would ultimately result in a better storage potential for the fruit treated with GA_3 (Coetzee and Theron 1999).

Effect of Gibberellin on next season fruit quality and harvest

The yield of the peach and nectarine trees was only decreased when the concentration of GA_3 reached 100 mg .L^{-1} or higher (González-Rossia et al. 2007). Another factor that contributes to the reduction in yield is that workers thin the fruit to be uniformly distributed along the shoot and do not compensate for the fact that there are fewer fruit in the proximal segment of the shoot. However, this is usually compensated for by the increase in fruit weight (González-Rossia et al. 2007). This should also be kept in mind during winter pruning as the removal of too many apical regions of shoots could lead to over thinning and a reduction in yield (González-Rossia et al. 2007). Coetzee and Theron (1999) reduced the number of reproductive buds by applying 90, 120, 150 and 180 mg L^{-1} GA_3 four weeks before harvest on 'Sunlite' nectarine, but the remaining flower buds were on the distal region of the shoots. Producers preferentially remove these fruit to reduce wind damage thereby decreasing the yield per tree without an increase in average fruit size (Coetzee and Theron 1999). When looking at the size distribution, a linear trend was found with increasing concentration. Therefore, an increased concentration resulted in an increased number of large fruit (Coetzee and Theron 1999).

In Japanese plums, González-Rossia et al. (2006) reported a decrease in the number of fruit harvested with applications of 75 mg L^{-1} or higher concentrations of GA_3, but it was compensated for by an increase in fruit weight. No detrimental effects were found on the fruit. Fruit firmness increased and peel colour was improved in 'Black Gold' (González-Rossia et al. 2006). García-Pallas et al. (2001) performed trials on 'Crimson Gold' nectarine applying GA_3 at 50, 100, 200 and 400 mg L^{-1} and reported reductions in the yield, with accompanying increases in fruit weight. Advanced maturity was found due to the decreased yield, along with higher levels of TSS and lower flesh firmness (García-Pallas et al. 2001).

Lenahan et al. (2006) applied 50 and 100 mg. L^{-1} at the end of stage I of fruit growth in cherries and reported an increase in fruit firmness and TSS. A decrease in bloom density and yield per tree was related and decreased linearly with increasing application rates (Lenahan et al. 2006). Although the TSS, fruit firmness and weight was increased, the crop value per tree was not significantly increased (Lenahan et al. 2006). The GA_3 reduced the yield by 71 and 95% when applications of 100 and 200 mg L^{-1} were used compared to 34 and 37% for the GA_{4+7} sprayed at the same concentrations (Lenahan et al. 2006).

Summary

It is by now well known that thinning is of high importance for the sustainable production of high quality fruit (Seehuber et al. 2011). Hand thinning is therefore required, but it contributes to a big share of the production cost for stone fruit producers (Baugher et al,. 2009). The search for an alternative has started as early as the 1950s, but neither mechanical nor chemical thinning has been implemented in the stone fruit industry, because of the fact that they have had inconsistent and unsatisfactory results (Rosa et al. 2008). If an alternative is found for hand thinning, it would have to be environmentally friendly, because consumers are demanding products that is environmentally safe (Damegrow and Blanke 2009). Hand thinning would not be replaced in its entirety, with hand thinning still needed to correct the final crop load (Damegrow and Blanke 2009).

Two machines that have been tested and showed encouraging results are the Darwin (Baugher et al. 2010) and BAUM (Damegrow and Blanke 2009). The Darwin was originally created by an organic apple grower (Baugher et al. 2010). It is a bloom thinner that can thin at different stages of bloom and result suggested that when it is used at different stages of bloom, it almost always give an increase in fruit size and fruit weight, compared to hand thinning alone at 40 – 50 dafb. The Darwin can be used from pink stage to petal fall of bloom (Baugher et al. 2010) at a rotor speed between 150 and 400 r.p.m. (Baugher et al. 2009) and producers would therefore have ±26 days to perform the thinning. This will help that labour-intensive work is more evenly distributed over the season, the efficiency of crop load management would be increased, and the use of ladders in the orchard will also be decreased (Baugher et al. 2010).

The BAUM is a novel device created by the Bonn University, Germany, to thin trees at flowering stage (Damegrow and Blanke 2009). It differs from the Darwin in that it has three rotors that can be set individually from each other (Seehuber et al. 2011). This allows the Baum to work on more complex tree structures with different tree architectures and planting densities (Hehnen et al. 2011). Removing 50% of the flowers have been achieved with a rotor speed between 300 to 420 r.p.m. and a tractor speed of 5 to 7 km h^{-1} (Damegrow and Blanke 2009) or at rotors speeds of 260 or 360 r.p.m. and a tractor speed of 2.5 km h^{-1} (Hehnen et al. 2011). Another positive is that the machine removes flowers in the tree periphery, but also removes flowers in the area close to the trunk where fruit of lesser quality develop (Solomakhin and Blanke 2010). For automation to become a reliable and economic option, the adapting of tree structures will be a key focus. This will mean that the structure of the trees would have to change from the current open centre trees, which are complex (Baugher et al. 2009), to more hedge type structures (Schupp et al. 2008).

Chemical thinning has been a viable option for pome fruit producers, but not for stone fruit producers where chemical thinners are rather scarce and/or often ineffective (Seehuber et al. 2011). The chemicals previously tested include caustic materials, growth regulators and photosynthetic inhibitors. Problems with these chemicals are that they are being withdrawn from many European countries because they are largely weather dependent (Damegrow and Blanke 2009), variable under different flower dynamics and tree ages (Hehnena et al. 2011), and are largely ineffective in the reduction of hand thinning (Baugher et al. 2009).

A plant hormone that has been tested for the reduction of flower buds through a negative effect on floral bud formation is GA (González-Rossia et al. 2007). GA also influences fruit quality, can delay maturity and improve fruit storability. The application of GA can increase fruit firmness and increase fruit weight (Lurie 2010). The application of GA will always be dependent on the cultivar and crop load (Byers 1989). The correct time of application will be an early application 47 days after full bloom (Byers 1989).

The use of GA to reduce the amount of flower buds in the next season by application in November through to January in the current season has a lot of advantages. It does not have any negative effects on fruit set, and the amount of hand thinning is reduced resulting in savings in production costs. The number of fruit left on the tree after hand thinning can also be increased, because the competition between fruit is removed earlier. This will result in an increase in yield (Southwick and Glozer 2000).

References

Aasted M, Dise R, Baugher TA, Schupp JS, Heinemann PH, Singh S. 2011. Autonomous mechanical thinning using scanning LIDAR. *ASABE Paper No.* 1111792*, St. Joseph, Mich.*

Bangerth F. 2000. Abscission and thinning of young fruit and their regulation by plant hormones and bioregulators. *Plant Growth Regulation* 31: 43-59.

Baugher TA, Elliott KC, Leach DW, Horton BD, Miller SS. 1991. Improved methods of mechanically thinning peaches at full bloom. *Journal of the American Society for Horticultural Science* 116(5): 766-769.

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

Baugher TA, Schupp J, Ellis K, Remcheck J, Winzeler E, Duncan R, Johnson S, Lewis K, Reighard G, Henderson G, Norton M, Dhaddey A, Heinemann P. 2010b. String blossom thinner designed for variable tree forms increases crop load management efficiency in trials in four United States peach-growing regions. *HortTechnology* 20(2): 409-414.

Baugher TA, Schupp JR, Lesser KM, Hess-Reichard K. 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 TA, Schupp J, Miller S, Harsh M, Lesser K, Reichard K, Sollenberger E, Armand M, Kammerer L, Reid M, Rice L, Waybright S, Wenk B, Tindall M, Moore E. 2008. Chemical and mechanical thinning of peaches. *Pennsylvania Fruit News* 88: 16-17.

Bertschinger L, Stadler W, Stadler P, Weibel F, Schumacer R. 1998. New methods of environmentally safe regulation of flower and fruit set and of alternate bearing of the apple crop. *Acta Horticultarae* 466: 65-70.

Bester M. Stander C, Oosthuizen M. 1994. Klein perskes en nektariens skep reuse probleme. *Deciduous Fruit Grower* 44 (7): 226-228.

Byers RE. 1989. Response of peach trees to bloom thinning. *Acta Horticultarae* 254: 125-132.

Coetzee JH, Theron KI. 1999. 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 on ‘Sunlite’ nectarines. *Journal of Southern African Society for Horticultural Sciences* 9: 13-17.

Costa G, Vizzotto G. 2000. Fruit thinning of peach trees. *Plant Growth Regulation* 31: 113-119.

Ebert A, Bangerth F. 1981. Relations between the concentration of diffusable and extractable gibberellin-like substances and the alternate- bearing behaviour in apple as affected by chemical fruit thinning. *Scientia Horticulturae* 15: 45-52.

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

Dennis Jr. FG. 2000. The history of fruit thinning. *Plant Growth Regulation* 31: 1-16.

Demirtas MN, Bolat I, Ercisli S, Ikinci SA, Olmez HA, Sahin M, Altindag M, Celik B. 2010. The effects of different pruning treatments on the growth, fruit quality and yield of 'Hacihaliloglu' apricot. *Acta Scientiarum Polonorum Hortorum Cultus* 9(4): 183-192.

Flore JA. 1992. The influence of summer pruning on the physiology and morphology of stone fruit trees. *Acta Horticulturae* 322: 257-264.

García-Pallas I, Val J, Blanco A. 2001. The inhibition of flower bud differentiation in 'Crimson Gold' nectarine with GA_3 as an alternative to hand thinning. *Scientia Horticulturae* 90: 265-278.

Glenn DM, Peterson DL, Giovannini D, Faust M. 1994. Mechanical thinning of peaches is effective postbloom. *HortScience* 29(8): 850-853.

González-Rossia D, Reig C, Juan M, Agustí M. 2006. The inhibition of flowering by means of gibberellic acid application reduces the cost of hand thinning in Japanese plums (*Prunus salicina* Lindl.). *Scientia Horticulturae* 110: 319-323.

González-Rossia D, Reig C, Juan M, Agustí M. 2007. Horticultural factors regulating effectiveness of GA_3 inhibiting flowering in peaches and nectarines (*Prunus persica* L. Batsch). *Scientia Horticulturae* 111: 352-357.

Greene DW. 2010. The development and use of plant bioregulators in tree fruit production. *Acta Horticultarae* 884: 31-40.

Hehnen D, Hanrahan I, Lewis K, Mcferson J, Blanke M. 2012. Mechanical flower thinning improves fruit quality of apples and promotes consistent bearing. *Scientia Horticulturae*. 134: 241-244.

Hortgro. 2012. Key deciduous fruit statistics 2012. *Hortgro supporting the horticultural industry.*

Kon MT, Schupp JR, Winzeler HE, Marini RP. 2013. Influence of mechanical string thinning treatments on vegetative and reproductive tissues, fruit set, yield, and fruit quality of 'Gala' apple. *HortScience* 48(1): 40-46.

Lenahan OM, Whiting MD, Elfving DC. 2006. Gibberellic acid inhibits floral bud induction and improves 'Bing' sweet cherry fruit quality. *HortScience.* 41(3): 654-659.

Lurie S. 2010. Plant growth regulators for improving postharvest stone fruit quality. *Acta Horticultarae* 884: 189-198.

Marini RP. 2003. Peach fruit weight, yield, and crop value are affected by number of fruiting shoots per tree. *HortScience* 38(4): 512-514.

Miller SS, Byers RE. 2000. Response of winter-injured peach trees to pruning. *HortTechnology* 10(4): 757-765.

Miller SS, Schupp JR, Baugher TA, Wolford SD. 2011. Performance of mechanical thinners for bloom or green fruit thinning in peaches. *HortScience* 46(1): 43-51.

Myers SC, King A, Savelle AT. 1993. Bloom thinning of 'Winblo' peach and 'Fantasia' nectarine with monocarbamide dihydrogensulfate. *HortScience* 28(6): 616-617.

Ngugi HK, Schupp JR. 2009. Evaluation of the risk of spreading fire blight in apple orchards with a mechanical string blossom thinner. *HortScience* 44(3): 862-865.

Reighard GL, Byers RE. 2009. Peach thinning. Available at

www.ent.uga.edu/peach/peachhbk/cultural/thinning.pdf.

Reighard GL, Henderson WG. 2011. Mechanical blossom thinning in South Carolina peach orchards. *HortTechnology* 19:755-761.

Rosa UA, Cheetancheri KG, Gliever CJ, Lee SH, Thompson J, Slaughter DC. 2008. An electro-mechanical limb shaker for fruit thinning. *Computers and electronics in agriculture* 61: 213-221.

Schupp JR, Baugher TA. 2011. Peach blossom string thinner performance improved with selective pruning. *HortScience* 46(11): 1486-1492.

Schupp JR, Baugher TA, Miller SS, Harsh RM, Lesser KM. 2008. Mechanical thinning of peach and apple trees reduces labor input and increases fruit size. *HortTechnology* 18(4): 660-670.

Seehuber C, Damegrow L, Blanke M. 2011. Regulation of source: sink relationship, fruit set, fruit growth and fruit quality in European plum (*Prunus domestica* L.)-using thinning for crop load management. *Plant Growth Regulation* 65: 335-341.

Solomakhin AA, Blanke MM. 2010. Mechanical flower thinning improves the fruit quality of apples. *Journal of Science of Food and Agriculture* 90: 735-741.

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

Southwick SM, Yeage JT, Zhou H. 1995. Flowering and fruiting in ‘Patterson’ apricot (*Prunus armeniaca*) in response to postharvest application of gibberellic acid. *Scientia Horticulturae* 60: 267-277.

Wertheim SJ. 1997. Chemical thinning of deciduous fruit trees. *Acta Horticultarae* 463: 445-462.

PAPER 1: EFFICACY OF MECHANICAL THINNING IN REDUCING HAND THINNING WHILE MAINTAINING FRUIT QUALITY IN NECTARINES

Abstract

The thinning of stone fruit is important in order to produce fruit of high quality, with the appropriate fruit size. Hand thinning contributes largely to the total production cost, as hand thinning is labour intensive, and labour costs are increasing. The efficacy of the Darwin 300™ at full bloom in reducing hand thinning requirements in 'Zephyr', 'Summer Fire' and 'Royal Sun' nectarine orchards was evaluated in consecutive seasons while also determining the effect on yield, fruit quality and return bloom. The trials in the case of 'Zephyr' and 'Summer Fire' were performed on the farm Tandfontein, in the Koue Bokkeveld area, South Africa, over the 2011/2012 and 2012/2013 seasons. Trees on 'SAPO 778' rootstock were planted in 2005 at a spacing of 4 x 1.5 m and are trained to a slender spindle. The 'Royal Sun' trial was performed on the farm Swartdam, near Riebeeck-Kasteel, South Africa, during the 2012/2013 season. The 'Royal Sun' on 'Flordaguard' was planted in 2009 at a spacing of 4 x 1.5m and the trees are trained to a slender spindle. The Darwin 300™ was used at a constant tractor speed of 4.8 km .h^{-1}, with mechanical thinning performed at full bloom, while the rotor speed varied from 200, 220 and 240 r.p.m. A randomised complete block design was used with nine trees per plot (using the central five trees for data) and five blocks in the case of 'Zephyr' and 'Summer Fire', with eight blocks used for the 'Royal Sun'. In the case of the 'Royal Sun', a hand bloom thinned control was also included. The time required to hand thin the five trees in the case of 'Zephyr', was consistently reduced by an average 43% in the 2011/2012 season and 33% in the 2012/2013 season. In the case of 'Summer Fire', the time required was reduced by an average of 32% in the 2011/2012 season and 35% in the 2012/2013 season. For the 'Royal Sun' this reduction was 44%, compared to 34% for the hand bloom thinned control. In the case of the 'Zephyr' in the 2011/2012 season, a negative linear trend was observed with increasing rotor speed in the time required to hand thin. This negative linear trend was also observed in the yield per tree in the 2011/2012 season. The yield per tree was consistently reduced and resulted in an average reduction of 21% in the 2011/2012 season and 27% in the 2012/2013 season. This reduction in yield was not significant in the 2011/2012 season in the case of 'Summer Fire', but a significant average reduction of 25% was found in the 2012/2013 season. In the case of 'Royal Sun' the Darwin 300™ bloom thinning resulted in an average reduction of 18% in yield per tree and the hand bloom thinned control in a 7% reduction in the yield per tree. This reduction in yield resulted in an increase in fruit size during both

seasons in the case of 'Zephyr' and 'Summer Fire'. For the 'Royal Sun' the increase in fruit size was the same for the mechanical thinning and hand bloom thinned control. In the case of 'Zephyr' the total soluble solids were increased in both seasons, but not in 'Summer Fire' and 'Royal Sun'. During the 2011/2012 season no negative effects were found in 'Zephyr' fruit, but in the 2012/2013 season the percentage of fruit cracking was significantly increased by all three machine treatments. Negative effects on fruit quality were not observed in 'Royal Sun' or in either season in 'Summer Fire'. In conclusion, mechanical thinning of nectarines with the Darwin 300™ has potential to reduce hand thinning, but it is important to not over thin trees with too high rotor speeds as it can reduce yield, increase fruit size too much and lead to fruit cracking and split pit. The optimal rate of thinning needs to be determined for each cultivar individually.

Keywords: *Prunus persica* L. Batsch, fruit size, labour cost, Darwin 300™

Introduction

Thinning is highly important to ensure sustainable production of high quality fruit (Seehuber et al. 2011). Current cultivars produce many flowers and set more fruit than is required for an economical crop (Costa and Vizzotto 2000). This implies that if thinning is not performed, the fruit would be small and of low quality (Dennis 2000). On average, only 7% of the flowers at bloom are required for an economical crop (Solomakhin and Blanke 2010, Hehnen et al. 2012).

The advantages of thinning are well known: A reduction in fruit numbers leads to bigger fruit (Dennis 2000) of higher quality (Costa and Vizzotto 2000), that are more evenly spaced (Rosa et al. 2008). The higher fruit quality includes an improvement in sugar, firmness, phenols and vitamin C (Seehuber et al. 2011). Other advantages include an increase in fruit weight, the advancement of fruit maturity, an increase in reproductive buds and a better fruit-to-shoot ratio (Costa and Vizzotto 2000). The cost of harvest could also be decreased due to the fewer fruit (Rosa et al. 2008). The implication of these positive effects is an increase in profit due to the increase in fruit quality, weight and size and therefore fruit marketability (Costa and Vizzotto 2000, Reighard and Byers 2009).

According to Seehuber et al. (2011), stone fruit benefit more from bloom thinning than pome fruit for the following six reasons: Stone fruit primary leaves are absent at the time of thinning unlike in apples and the fruit usually develop over a shorter period. Stone fruit also do not exhibit strong "June drop", but may have a severe pre-harvest drop. The threshold that has to be exceeded before the fruit grow faster and final fruit weight and sugar increase is much lower than in pome fruit.

Another problem is that the upper saturation threshold for fruit growth, i.e. the level of thinning above which no further gain in fruit size is achieved, is reached at 60% removal, which is a relatively low level of thinning. Removal of more fruit will not result in a further gain in fruit size. Crop load and therefore source: sink relationships, are difficult to manipulate in stone fruit, as stone fruit fail to react to chemical treatments that easily thin pome fruit (Seehuber et al. 2011).

Considering the above, thinning is a necessity in most commercial peach, apricot, prune, plum and nectarine cultivars (Southwick and Glozer 2000). It is still mostly done by hand (Rosa et al. 2008). Hand thinning contributes largely to the production costs of stone fruit. The reason for this is that hand thinning is labour intensive (Baugher et al. 2009). In addition, labour is becoming more difficult to obtain (Damegrow and Blanke 2009), unproductive in certain areas (Baugher et al. 2009) and therefore costs are increasing (Costa and Vizzotto 2000). Therefore, although hand thinning is effective in reducing the number of flowers or fruitlets, between 100 and 500 hours of labour per hectare are required, depending on tree size, flower density and thinning intensity required (González-Rossia et al. 2007).

The search for an alternative to hand thinning started as early as the 1950's, but neither chemical nor mechanical thinning have been widely implemented because of inconsistent and unsatisfactory results (Rosa et al. 2008). In 1981, data showed that the expensive hand thinning still produced better results than mechanical thinning (Rosa et al. 2008). Should an alternative be found for hand thinning as main thinning method, hand thinning would still be used after final fruit drop to remove diseased and under-sized fruitlets (Damegrow and Blanke 2009).

The awareness of the need to protect the environment has grown substantially in fruit production (Damegrow and Blanke 2009). Mechanical thinning has an advantage over chemical thinning in that it is more environmentally friendly. This and the fact that labour is limited and expensive have opened the door for mechanical thinning to be re-evaluated (Baugher et al. 2008). In addition, since the thinning efficacy of mechanical thinning can be observed directly after the thinning, the thinning severity can be adjusted while thinning is taking place (Baugher et al. 2009). When used correctly, mechanical thinning also generally distributes fruit more evenly over the shoot and also leaves flowers on parts of the shoots where the potential high quality fruit development is greater (Byers 1989).

A number of mechanical thinners have been evaluated over the past few years. These include labourers with rakes, dragging ropes (Rosa et al. 2008), trunk-shakers (Reighard and Byers 2009), low-frequency electrodynamic limb shakers, high-pressure water streams, rotating curtains (Schupp et al. 2008), spike-drums (Baugher et al. 2008) and impact shakers (Schupp et al. 2008) as well as the

Darwin 300™ (Baugher et al. 2010; Schupp and Baugher 2011) and the BAUM (Bonner Ausdünnungsmashine) (Damegrow and Blanke 2009, Hehnen et al. 2012).

The original Darwin was called a wire-machine and was designed by H. Gesseler in Friedrichshafen-Hirschblatt, Germany (Bertschinger et al. 1998). The Darwin™ was further developed by Fruit Tec Pty (Ltd.) in Deggenhausertal, Germany, for thinning of pyramid-shaped apple trees during bloom (Baugher et al. 2010, Schupp and Baugher 2011). The device is mounted on a tractor with a three-point hitch, fork mount or a bolt-on mount (Baugher et al. 2009) and has a three meter vertical spindle (Schupp et al. 2008; Baugher et al. 2010, Schupp and Baugher 2011). The spindle can be tilted 30° in either direction from the centre (Schupp et al. 2008, Baugher et al. 2010, Schupp and Baugher 2011). Attached to the spindle are a total of 36 steel plates that secure 648 plastic cords (Schupp et al. 2008, Ngugi et al. 2009) measuring at 50 cm each (Schupp et al. 2008, Baugher et al. 2010). The spindle is driven by the hydraulic system of the tractor and can be regulated by adjusting the control valve, which is situated on the tractor (Schupp et al. 2008, Baugher et al. 2010, Schupp and Baugher 2011). Intensity of thinning can be adjusted by changing the rotational speed of the spindle (Schupp et al. 2008, Baugher et al. 2010, Schupp and Baugher 2011), the speed of the tractor (Schupp et al. 2008, Baugher et al. 2009, Schupp and Baugher 2011), or the arrangement of the plastic chord (Schupp and Baugher 2011). When higher fruit set is expected the spindle speed needs to be increased to get satisfactory results (Kon et al. 2013). In order to conform to different shapes of trees, the height of the spindle and angle can be changed (Baugher et al. 2009). The rotor speed can be adjusted between 150 and 400 r.p.m. (Baugher et al. 2009). Keeping the spindle parallel to the vertical plane of the tree canopy (Schupp et al. 2008), 10 cm away from the trunk (Aasted et al. 2011), will ensure a uniform thinning response in the upper and lower canopy (Schupp et al. 2008). To achieve optimal thinning inconsecutive years, the spindle position should be kept the same (Kon et al. 2013).

In this paper we report on the efficiency of the Darwin 300™ string thinner at full bloom in reducing hand thinning requirement in nectarine orchards while also evaluating the effect on yield, fruit quality and return bloom.

Materials and methods

Plant material and site description

During 2011/2012 and 2012/2013, trials were performed on the farm Tandfontein (33°46’01.42”S; 19°14’13.35”E), in the Koue Bokkeveld area, South Africa on the cultivars Zephyr and Summer Fire. The trees on the rootstock ‘SAPO 778’ were planted in 2005, at a spacing of 4 x 1.5m and are trained to a slender spindle. The 2012/2013 trial was repeated on the same trees as the previous year. A trial was also performed during 2012/2013 on 'Royal Sun' at Swartdam (33°25'28.32"S; 18°53'48.70"E) near Riebeeck-Kasteel, in the Western Cape, South Africa. The trees on the rootstock 'Flordaguard' were planted in 2009 at a spacing of 4 x 1.5m and are trained to a slender spindle. Orchard histories are summarized in Table 1a.

Experimental design and treatments

In all trials tractor speed was kept constant at 4.8 km $.h^{-1}$. A hand thinned control (thinned at fruitlet stage) was used for all cultivars, and for the Royal Sun a bloom hand thinned control was added. Mechanical thinning of 'Zephyr', 'Summer Fire' and 'Royal Sun' was performed at full bloom at rotor speeds of 200, 220 and 240 r.p.m. Machine thinning, hand thinning and harvest dates are summarised in Table 1b.

A randomized complete blocks design was used with five replicates for the 'Zephyr' and 'Summer Fire' and eight replicates for the 'Royal Sun'. For each replicate a plot consisting of nine trees was used of which the middle five trees were used to record data.

Data collection

For 'Zephyr', 'Summer Fire' and 'Royal Sun' in the 2011/2012 and 2012/2013 seasons, three shoots per tree in the five-tree plots were tagged before thinning with the Darwin 300™. The number of flowers on tagged shoots was counted before and after thinning to determine the percentage of flowers removed. For 'Zephyr' and 'Summer Fire' in 2012/2013 the percentage of fruit set was also determined before fruitlet thinning. For all the cultivars the efficacy of thinning was determined by recording the time required to complete hand thinning per plot as well as counting the number of fruitlets thinned during commercial hand thinning. In the 'Royal Sun' trial, the time required to complete bloom thinning by hand per plot was also determined for the hand-bloom thinning treatment. The thinned fruitlets were also checked for any defects caused by the mechanical thinning. At commercial harvest the total yield per five-tree-plot was recorded (expressed as yield per tree) and 25 fruit were sampled at each harvest date and bought to our laboratory. Here the 25 fruit were evaluated for any external defects. In addition, the following were determined per fruit: weight, length, diameter, firmness and total soluble solids concentration (TSS). Fruit firmness was determined on opposite, pared sides of the fruit using a 11.1 mm probe on a GÜSS texture analyser (Guss electronic model GS 20, Strand, South Africa), while TSS was determined using a ATAGO®

pocket refractometer (PAL-1, The Front Tower Shiba Koen, 23rd floor 2-6-3 Shiba-Koen, Minato-ku, Tokyo 105-0011. Japan). During winter, just prior to dormant pruning, the tree height (h), in-row width (ir) and the row width (r) of the tree, were measured to determine the tree volume using the following formula:

$$(PI\left(\left(\frac{average(ir,r)}{2}\right)^2\right) * h)/1000)$$

After completion of these measurements, trees were pruned commercially and prunings weighed. The pruning dates are summarized in Table 1.

Statistical analysis

Data were analysed by ANOVA using the linear models procedure of SAS Enterprise guide 5.1 (SAS Institute Incorporated, 100 SAS Campus Drive Cary, North Carolina 27513-2414, USA), and using the LSD test when the F statistic indicated significance at $P < 0.05$.

Results

Hand thinning requirement

During the 2011/2012 season the percentage of flowers removed in the case of 'Zephyr' showed a significant linear increase with an increase in rotor speed from 200 to 240 r.p.m. (Table 2). A linear decrease was also found in the time required to hand thin the five trees per plot, with the increasing rotor speed (Table 2). All three rotor speeds significantly reduced the time required to thin cmapred to the control (Table 2). With the time required to hand thin being reduced by 54% by the 240 r.p.m. treatment compared to the non-machine hand thinned control (Table 2). The percentage reduction in number of fruitlets removed followed the same decreasing trend (Table 2). In the case of 'Summer Fire' different rotor speeds of the Darwin 300™ had no significant effect on the percentage of flowers removed (Table 2). There was also no significant effect between the different rotors speeds of the Darwin 300™ for the time required for hand thinning, and number of fruitlets removed (Table 2). There was, however, a linear increase in the percentage of flowers removed with increasing rotor speed (Table 2), even though the 240 r.p.m. treatment only removed 59% of the flowers compared to the 69% in the case of 'Zephyr'. The 240 r.p.m. treatment decreased the hand thinning time required and the number of fruitlets removed by 38% and 54%, respectively, compared to the control (Table 2).

During the 2012/2013 season, there was no significant difference in the percentage flowers removed between rotor speeds in the case of 'Zephyr' and 'Royal Sun', while in 'Summer Fire' a linear increase was found with increasing rotor speed (Table 3). There was no effect on fruit set on the tagged shoots between the rotor speeds used in both 'Zephyr' and 'Summer Fire' (Table 3). The time required to hand thin 'Zephyr' was significantly reduced by the 200 and 240 r.p.m. treatments compared to the control, but the different rotor speeds did not differ significantly from each other (Table 4). For the number of fruitlets removed, the three rotor speeds differed significantly from the non-machine control, but did not differ significantly from each other (Table 4). The linear increase in the percentage of flowers removed in 'Summer Fire' with an increase in rotor speed, did significantly decrease the time required to hand thin, but all mechanical thinning treatments reduced hand thinning time and the number of thinned fruitlets compared to the control (Table 4). The three machine treatments reduced the time required to hand thin by 29, 35 and 40%, respectively. The effect was even greater for the number of fruitlets removed with reductions of 47, 56 and 57%, respectively (Table 4). In case of 'Royal Sun' the machine treatments reduced the number of fruitlets removed compared to the hand bloom-thinned control (Table 4). The number of fruitlets that remained until the fruitlet thinning stage was 4394 per five-tree-plot in the hand bloom-thinned control, while it was only 3700, 3535 and 3990, respectively for the three machine treatments (Table 4). This resulted in a 36, 33 and 31% reduction in the time required to thin for the three machine treatments, compared to the 13% for the hand bloom-thinned control. The effect was even greater for the number of fruitlets removed with reductions of 44, 47 and 40% for the three machine treatments respectively, compared to 36% for the hand bloom thinned control (Table 4).

Effect on yield

In the case of 'Zephyr' in the 2011/2012 season the yield per tree (kg cm^{-2}, trunk cross sectional area) at the first harvest was significantly reduced by the 220 and 240 r.p.m. treatment compared to the control, but not by the 200 r.p.m. treatment, while at the second harvest date the yield per tree was significantly reduced by the 220 and 240 r.p.m. treatments, compared to the control, but not by the 200 r.p.m. treatment (Table 5). There was, however, a linear reduction in the yield per tree at the first harvest and total harvest with an increase in the rotor speed (Table 5). The percentage reduction in the total yield compared to the non-machine thinned control was 26.7, 26 and 10% for the 240, 220 and 200 r.p.m. treatments, respectively (Table 5). The yield per tree in the case of 'Summer Fire' was reduced in 2011/2012 although not significantly (Table 6). In 'Zephyr' (2011/2012) the 33.4% of the total yield was harvested at the first harvest date for the 200 r.p.m. treatment compared to the 31.6% in the control and the 240 r.p.m. treatment, and 25.9% for 240 r.p.m. treatment (Table 5). For 'Summer Fire' the percentage of yield harvested for the first harvest date was the highest with 79.2%, for the control and 76.9, 76.3 and 77.8% for the machine treatments, respectively (Table 6).

During the 2012/2013 season, all mechanical thinning treatments significantly reduced the yield of 'Zephyr' at the first harvest (Table 7). The yield per tree for the second, third and fourth harvests was not significantly affected, although the yield for the three machine treatments tended to be lower than that of the non-machine thinned control (Table 7). The 220 and 240 r.p.m. treatments reduced the total yield per tree compared to the control, although it did not differ significantly from the 200 r.p.m. treatment. The percentage reduction compared to the non-machine thinned control in total yield was 26, 24 and 38% for the 200, 220 and 240 r.p.m. treatments respectively (Table 7). The percentage of the total yield harvested at the first harvest date was the highest for the control at 20.2% and 17.1, 16.5 and 16.7% for the machine treatments, respectively in 'Zephyr' (Table 7). The yield per tree in 'Summer Fire' was not significantly reduced for the first, second and the third harvest dates. At the fourth harvest date, the 220 and 240 r.p.m. treatments significantly reduced the yield per tree compared to the control, but not compared the 200 r.p.m. treatment (Table 8). Total yield per tree was significantly and to the same extent reduced by all three machine-thinned treatments (Table 8). The percentage reduction in total yield was 32, 24 and 21%, for the 240, 220 and 200 r.p.m. treatments, respectively (Table 8). 35.1 and 41.1% of the total harvest was harvested at the first harvest date for the 200 and 220 r.p.m. treatments, respectively, compared to 25.3 and 28.2% for the control and the 240 r.p.m. treatments, respectively (Table 8). In the case of 'Royal Sun' no significant differences were found in yield per tree at the first and second harvest dates (Table 9). At the third harvest date the hand bloom-thinned control and all mechanical thinning treatments reduced the yield per tree but did not differ from each other. The total yield was significantly reduced by all the mechanical thinning treatments (Table 9). The hand bloom-thinned control did not differ significantly from the fruitlet thinned control or from the 200 and 240 r.p.m. treatments (Table 9). The percentage reduction in yield for the hand bloom-thinned control and the 240, 220 and 200 r.p.m. treatments was 7, 16, 21 and 18%, respectively (Table 9). For 'Royal Sun', 46.2% of the total harvest was harvested at the first harvest date for the bloom-thinned control, compared to 46.2, 43.4 and 43.8% for the three machine treatments, respectively (Table 9). This was a higher percentage than was harvested for the control, which had 37% at the first harvest.

Fruit size

During the 2011/2012 season, machine thinned treatments significantly increased fruit size in 'Zephyr' at each harvest date and in total as indicated by fruit weight, fruit length and fruit diameter

(Table 10, 11 and 12). The increase in fruit weight, length and diameter was linear with an increase in rotor speed for the first harvest date and in total (Table 10, 12). Fruit weight and diameter also increased linearly with increasing rotor speed at the second harvest (Table 11). At the first harvest fruit weight was increased by the 240 r.p.m. compared to the 200 r.p.m. (Table 10). In the case of the fruit length and diameter the 220 and 240 r.p.m. treatments significantly increased fruit weight compared to the 200 r.p.m. treatment (Table 10). The 240 r.p.m. treatment significantly increased fruit weight and diameter compared to the 200 r.p.m. treatment at the second harvest date (Table 11). The machine thinned treatments not differing significantly from each other at the second harvest date (Table 11). The 240 r.p.m. treatment significantly increased fruit weight, length and diameter of the total yield compared to the 200 r.p.m. treatment (Table 12). The fruit size of 'Summer Fire' was not significantly affected by machine thinning (Table 13, 14, 15).

In the 2012/2013 season, the fruit size, machine treatments had no effect on the fruit size of 'Zephyr' at harvest one, two and four, but significantly increased fruit size at the third harvest date (Table 16-19). The fruit weight and diameter was significantly increased by all three machine treatments compared to the control (Table 18). Machine thinning did not affect 'Zephyr' fruit size for the total yield (Table 20). In the case of 'Summer Fire', the machine thinning treatments had no effect on fruit weight, length and diameter at any harvest date or for the total harvest (Table 21-25). There were also no significant treatment effects on the fruit weight, length or diameter of 'Royal Sun' at the first and third harvest dates, but fruit weight and diameter were increased by all three machine treatments compared to the fruitlet thinned control at the second harvest and for total harvest (Table 26-29). The hand bloom-thinned control increased fruit weight and diameter compared to the fruitlet-thinned control for total harvest and also increased fruit diameter at the second harvest (Table 27, 29). The fruit size for the three machine treatments -did not differ significantly at any harvest, except for an increase in fruit diameter at the second harvest for the 240 compared to the 200 r.p.m. treatment (Table 27-29). Also at the second harvest date, the fruit diameter of the 240 r.p.m. treatment was significantly higher than that of the hand bloom-thinned control (Table 27).

Fruit quality

During the 2011/2012 season, the fruit firmness of 'Zephyr' at the first harvest was lower for the 200 and 220 r.p.m. treatments compared to the control and the 240 r.p.m. treatment (Table 10). Only the 200 r.p.m. treatment differed significantly from the control. For the whole crop, the fruit firmness increased linearly, with an increase in the rotor speed (Table 12). Here the fruit firmness was significantly increased by the 240 r.p.m. treatment compared to the control and the 200 r.p.m. treatment, with the 240 and 220 r.p.m. treatments not differing significantly from each other (Table 12). No other effects on fruit quality were observed for any of the harvest dates and for the total crop (Table 10-12). The split pit in 'Summer Fire' was reduced by the 240 and the 200 r.p.m. treatments for the fruit harvest and in the total crop (Table 13, 15). No other effects on fruit quality parameters were observed (Table 13-15).

During the 2012/2013 season, machine thinning significantly increased the TSS of 'Zephyr' at the first harvest date and for the total crop (Table 16, 20). The TSS showed a quadratic response to increasing rotor speed, flattening off at or decreasing above 220 r.p.m. for the first harvest and total crop (P=0.0757), respectively (Table 16, 20). The lower rotor speeds increased the TSS at the second harvest date compared to the control and the 240 r.p.m. treatment (Table 17, 20). A significant increase in the percentage of split pit was found for the 200 and 220 r.p.m. treatments for the first harvest date (Table 16) and the trend (P=0.0850) was also found for the combined data with the 200 and 220 r.p.m. treatments increasing the percentage of split pit by 12%, compared to the control (Table 20). For the fourth harvest date the three machine treatments increased the percentage of fruit cracking by 7.7% compared to the control (Table 19). For the combined data the 200 and 220 r.p.m. treatments increased the percentage of cracked fruit by 9 and 8%, respectively, with the 240 r.p.m. treatment not differing significantly from the control (Table 20). These two treatments also appeared to have increased fruit cracking at the first (P=0.0698) and second (P=0.0547) harvest (Table 16, 17). Fruit cracking seemed to decrease with an increase in rotor speed (Table 16-20). There were no significant effects on the fruit firmness, TSS, percentage fruit cracking and percentage of split pit for any of the 'Summer Fire' harvest dates (Table 21-25), or on the fruit firmness, TSS and the percentage of split pit for the 'Royal Sun' harvest dates (Table 26 -29).

Pruning and tree volume

In the 2011/2012 season, the winter 2012 pruning weights in 'Zephyr' was significantly increased by the 220 and 240 r.p.m. treatments (Table 30). The weight of prunings removed for the 200 r.p.m. treatment did not differ significantly from the control. Treatments had no effect on pruning weights in 'Summer Fire' (Table 30). The tree volume was not significantly increased by machine thinning in 'Zephyr' or 'Summer Fire', although increasing linear trends with an increase in rotor speed was observed (P=0.0810 and 0.0726, respectively) (Table 30). Treatments did not affect tree volume and the weight of prunings removed during the 2013 winter in 'Zephyr' and 'Summer Fire' (Table 31).

Discussion

Generally the thinning intensity increased with increasing spindle speed from 200 to 220, to 240 r.p.m. in all three cultivars, with the Darwin 300™ removing up to 70% of the flowers at the 240 r.p.m. This concurs with Schupp et al. (2008), Baugher et al. (2010), Schupp and Baugher (2011) and Kon et al. (2013) who also found that increased spindle speed increased thinning efficacy. The percentage flowers removed in 'Zephyr' was higher than in 'Summer Fire' during 2011/2012 season and in the 'Royal Sun' during the 2012/2013 season. The differences between cultivars could be related to differences in flower architecture as 'Zephyr' and 'Royal Sun' have large, showy flowers while 'Summer Fire' has smaller, less showy flowers with small petals (Fig. 1). The reason why 'Royal Sun' was not as effectively thinned could be because the thinning date was slightly after full bloom and petals were thinned rather than flowers. However, Baugher et al. (2010) when performing thinning at petal fall, found that the thinning efficiency was the same as for the thinning performed at full bloom. Apart from the flower architecture the development of the abscission zone or the length of petioles might differ between cultivars. In addition tree architecture differs between cultivars and this may lead to differences in branch stiffness (Schupp et al. 2008). In our trials, the chosen orchards were not planted and trained with mechanisation in mind. Therefore the orchard floor surface was uneven in places. This could have led to over or under thinning as the tractor moved into or away from the tree row as the tractor drove down the alley. Another factor that could have led to under thinning is that the trees were taller than three meters and therefore the spindle would not have been able to reach the top of the trees. This was especially seen with the 'Royal Sun'.

The effect on thinning intensity resulted in differences in the time required for hand thinning which, in the case of 'Zephyr' was reduced between 23 to 54% for the two seasons. In the case of 'Summer Fire' the time required for hand thinning was reduced by 22 to 40% and for 'Royal Sun' 25 to 30% compared to the control. Schupp et al. (2008) found a 24 and 42% reduction in the required hand thinning time, on 'Redhaven' peaches, after mechanical thinning with the Darwin 300™ at 20 and 80% full bloom, respectively (Schupp et al. 2008). Baugher et al. (2010) similarly found a reduction in the hand thinning time required of 51 and 41% for 'Sugar Giant' (peach) and 42 and 22% in 'Artic Sweet' (nectarine) over two years. To achieve optimal thinning in consecutive years, the spindle position needs to be consistent (Kon et al. 2013). The removal of entire flower clusters in pome fruit has been described as an occasionally occurrence, and more often seen in the first season of using the Darwin in an orchard (Kon et al. 2013). This could be the reason why for 'Zephyr' the average reduction in the time required to hand thin was 43% in the first season, but only 33% for the second season. This effect was not found for the 'Summer Fire'. It is interesting that the reduction in the requirement for hand thinning was more evident in the number and weight of fruitlets removed, rather than in the hand thinning time required. This could be because of the effect of moving ladders. The time taken for a labourer to move the ladder from one tree to the next and to get up and down the ladder is not reduced by mechanical thinning. The time taken on the ladder is reduced since fewer fruit need to be thinned, but this has a smaller effect on the required hand thinning time than the time it takes to move the ladder. This was confirmed by Calvin and Martin (2010), who found that only 30% of the total time spent during harvest, was spent picking fruit. The rest of the time is spent positioning ladders, climbing up and down ladders and unloading bags of fruit (Calvin and Martin 2010). Their study looked at the harvesting of apples, but this effect would be the same for any cultural practise utilising ladders, would it be hand thinning, summer or winter pruning, or harvest. They suggested that a motorized platform could enable workers to devote more of their time to picking the fruit and therefore in our case to fruit thinning. Focus in further studies could therefore concentrate on the elimination of ladders through the use of platforms to increase the efficiency of hand thinning.

The reduction in the time required for follow-up hand thinning was also correlated to the reduction in crop load (Baugher et al. 2010). The yield of the ‘Zephyr’ was significantly reduced by 26.1 and 26.8% by the 220 and 240 r.p.m. rotor speeds, respectively during the 2011/2012 season. In the 2012/2013 season, the 240 r.p.m. rotor speed reduced the yield significantly by 38.1%. This was similar to the reduction in the hand thinning time, where there was a linear reduction in 2011/2012 for the hand thinning time and yield per tree. The same effect was seen in the 2012/2013 season, where the 240 r.p.m. rotor speed significantly reduced the yield per tree and the hand thinning time. Interestingly for the ‘Summer Fire’ in the 2011/2012 season, there was a significant reduction in the hand thinning time by the 200 and 240 r.p.m. rotor speeds, but not the 220 r.p.m. rotor speed. This reduction was also found in the yield per tree, albeit not significantly. The 220 r.p.m. rotor speed reduced the yield per tree and the hand thinning time the least. This effect was also found for the 2012/2013 season in ‘Zephyr’. To achieve optimum thinning efficiency the spindle needs to be kept within 10 cm of the trunk (Schupp et al. 2008). Aasted et al. (2011) reported that the current method of performing thinning with the Darwin 300™ is not effective, because of the fact that the driver needs to weave in and out of the trees, to keep constant engagement between the spindle and the canopy. Therefore, an uneven orchard floor or a canopy that is not uniform, with permanent shoots growing into the tractor row, would require the tractor driver to constantly adjust the driving line. This could have resulted in the fact that the 220 r.p.m. rotor speed had a lower thinning efficiency than the 200 r.p.m. rotor speed due to the low number of repetitions, variation could have differed between treatments. During the 2012/2013 season of the 'Summer Fire', the hand thinning time was significantly reduced by all three treatments. This was not found for the yield per tree in that, only the 240 r.p.m. rotor speed significantly reduced the yield per tree. When the thinning effect of the Darwin 300™ is compared to bloom thinning by hand, it is evident that thinning with the Darwin 300™ is not a selective thinning practise. This was confirmed by Baugher et al. (2010) stating that the Darwin is a non-selective thinner that only removes those flowers which it touches. Overlapping branches therefore has a negative effect on the thinning efficiency (Baugher et al. 2009). The interior of the tree is thinned less effectively than shoots that are parallel to or extending out into the tractor row (Schupp et al. 2008) and which might be over thinned. The Darwin 300™ decreased the number of 'Royal Sun' fruitlets that had to be removed with follow-up hand thinning and also decreased the yield per tree by 0.016 kg cm^{-2} compared to the bloom thinned control, although the difference between these treatments were not significant. The Darwin 300™ probably over-thinned the outer canopy and under-thinned the inner canopy. Compared to the bloom thinning treatment, the Darwin 300™ thus reduced the fruit load in the outer canopy while the inner canopy was thinned to the same cropping level during follow-up hand thinning. This explains the slightly lower yield for the mechanical thinning treatment. The hand labour is therefore more selective than the Darwin 300™ in removing the unwanted flowers from the tips of shoots and the flowers closer to the trunk. Therefore, although the Darwin 300™ reduced the number of fruitlets reduced more than the hand labour at bloom, the Darwin 300™ could not only remove the unwanted flowers and therefore over thinned, resulting in an yield decrease.

The yield per tree in our study was presented as yield efficiency (kg per trunk cross sectional area). The decrease in the yield per tree could therefore be misleading, if as we found, the bloom thinning resulted in an increase in tree growth. Therefore, the treated trees were larger, resulting in a lower yield efficiency, although the total kilograms harvested per tree may not have differed significantly.

A yield decrease is acceptable if there is an accompanied increase in fruit size and therefore an increase in the income per fruit (Kon et al. 2013). However, if the fruit size is increased above the desired size, the number of fruit left on the tree after thinning should be increased. Here the cultivar potential and characteristics are highly important. According to García-Pallas et al. (2001), certain cultivars are sensitive to spacing of fruit on the shoots, meaning that fruit of these cultivars will not reach the desired size if too many fruit are left on individual shoots. Therefore, if extra fruit are left on certain positions due to non-selective thinning, the fruit will not achieve the desired size. These cultivars that are sensitive to spacing of fruit therefore require a uniform fruit distribution along the shoots (García-Pallas et al. 2001). Kon et al. (2013) found an increase in fruit size, but the overall increase in fruit weight was less than four grams for the different treatments on apples. Baugher et al. (2010) performed trials on 'Sugar Giant' peach and 'Artic Sweet' nectarine and reported an increase in fruit size, with the fruit in the seven centimetres and greater size category being increase for both cultivars. We found an increase in 'Zephyr', 'Summer Fire' and 'Royal Sun' fruit size; however the increase was only significantly for 'Zephyr' during the 2011/2012 season and for 'Royal Sun' during the 2012/2013 season. The average fruit weight, length and diameter were increased by more than 37.5 g, 4.6 mm and 5.1 mm, respectively for the 'Zephyr' during the 2011/2012 season. In the 'Royal Sun' the fruit weight was increased by 4.8, 4.5 and 4.4 g for the three rotor speeds, respectively. In comparison, the bloom thinned control increased fruit weight by 6.7 g. The fruit diameter in 'Royal Sun' was increased by 1.4, 1.3 and 1.5 mm, compared to the hand thinned control which increased the fruit length by 1.7 mm. The fruit weight of the 'Zephyr' increased by an average of 25.2 g in the 2012/2013 season. For the 'Summer Fire' the average fruit weight increased by an average of 22.5 g in 2011/2012 season and -0.5 g in the 2012/2013 season. The effect on the fruit size was therefore greater during the first season compared to the second for both the cultivars. This could be ascribed to the fact that thinning treatments had less of an effect on the yield per tree during the second season. The increases in fruit size and the decrease in hand thinning time required through bloom thinning, increased the value of the two cultivars far beyond that of hand thinning at the fruitlet stage alone (Schupp et al. 2008, Baugher et al. 2010). Earlier machine thinning increases the portion of the crop in the more lucrative larger size categories. The increased profitability achieved with the Darwin is due more to this increase in the desired fruit sizes than to the saving in labour costs (Baugher et al. 2010).

Fruit on mechanically thinned trees matured earlier in 'Summer Fire' and 'Royal Sun' during the 2012/2013 season as was found by Myers et al. (1993). For 'Summer Fire' the yield per tree harvested at the first harvest was increased by 8.1, 15.7 and 3.2% for the lowest, middle and highest rotors speed, respectively. The same effect was found in the 'Royal Sun' where the percentage of the total yield harvested at the first harvest was increased by 8.8, 9.2, 6.6 and 7.1% for the bloom thinned control, lowest, middle and highest rotor speeds, respectively. Maturity shift to an earlier window in the fruit market could aid producers in certain early cultivars. The TSS was significantly increased in the 'Zephyr' during the 2012/2013 season. The thinning performed at bloom, compared to the "normal practise" of removing fruit at 40-50 days after full bloom (±20 mm diameter) resulted in the increase in the fruit size and TSS. Costa and Vizzotto (2000), Hehenen et al. (2012), Rosa et al. (2008) and Seehuber et al. (2011) found similar increases in fruit size and TSS, but also in firmness. The latter was however not the case in our trials on 'Zephyr', 'Summer Fire' and 'Royal Sun'.

During 2012/2013, split pit was not significantly increased, but still was negative consequence of mechanical thinning in 'Zephyr'. The result for the combined harvest data showed that the lowest and middle rotor speed increased the percentage of split pit by 12% each. The highest rotor speed only increased the percentage split pit by 4%. The inverse was found for the 'Summer Fire' where a significant decrease in the percentage split pit was found at the first harvest date in 2011/2012. There was also no significant effect found in the 'Summer Fire' in 2012/2013. In general, split pit was lower in 'Summer Fire' than in 'Zephyr'. The 'Royal Sun' also showed no significant effects from the mechanical thinning on split pit. Split pit is probably caused by an increase in fruit growth rate during stage I and II of fruit growth before pit hardening (Day and De Jong 1998). In 'Zephyr' we found larger fruit following mechanical thinning and this probably means faster fruit growth due to removal of excess fruit by thinning and therefore leading to split pit. In 'Summer Fire', mechanical thinning was less effective and therefore did not lead to an increase in split pit. Split pit can usually not be seen before harvest and has a negative effect on fruit quality post-harvest (Day and De Jong 1998) as such fruit will soften quicker than those without split pit (Crisosto et al. 1997). Mechanical thinning should therefore be applied carefully so as not to lead to over thinning thereby increasing fruit growth too much before pit hardening and resulting in split pit.

The percentage cracked fruit was significantly increased at 200 and 220 r.p.m. in 'Zephyr' in 2012/2013. This was not found in 'Summer Fire' or 'Royal Sun', but the fruit size in 'Zephyr' was generally much larger and was further increased by mechanical thinning. The strong fruit growth in this cultivar probably lead to cracking as it is known that fruit cracking can be caused by fast growth during stage III (Kasai et al. 2008). Kasai et al. (2008) performed work on 'Fuji' apples and found that internal ring cracking was increased by an increased fruit growth rate. The first symptoms of internal ring cracking were found 92 days after full bloom, with a rapid increase in the symptoms 120 days after full (Kasai et al. 2008).

The tree volume was not significantly increased, but a general trend in increased tree volume was found following mechanical thinning. This was also reflected in the weight of winter prunings. The weight of winter prunings was significantly increased for 'Zephyr' in 2011/2012 following the aggressive thinning by the highest rotor speed. This was not significant for 'Zephyr' in 2012/2013, or for the 'Summer Fire' in both seasons. This increase in tree size can be ascribed to the allocation of more dry matter to vegetative growth due to the earlier thinning with the Darwin 300™. The reproductive sink is reduced and therefore the vegetative sink strength was increased. This could also therefore be a tool to overcome alternate bearing as suggested by Damegrow and Blanke (2009). The reproductive bud induction should be promoted and the fruit-to-shoot ratio improved (Costa and Vizzotto 2000).

In conclusion, mechanical thinning of nectarines with the Darwin 300™ has potential to reduce hand thinning, but it is important to not over thin trees with too high rotor speeds as it can reduce yield, increase fruit size too much and lead to fruit cracking and split pit. The optimal rate of thinning needs to be determined for each cultivar individually.

References

Aasted M, Dise R, Baugher TA, Schupp JS, Heinemann PH, Singh S. 2011. Autonomous mechanical thinning using scanning LIDAR. *ASABE Paper No*. 1111792, St. Joseph, Mich.

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

Baugher TA, Schupp JR, Lesser KM, Hess-reichard K. 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 TA, Schupp J, Miller S, Harsh M, Lesser K, Reichard K, Sollenberger E, Armand M, Kammerer L, Reid M, Rice L, Waybright S, Wenk B, Tindall M, Moore E. 2008. Chemical and mechanical thinning of peaches. *Pennsylvania Fruit News* 88: 16-17.

Bertschinger L, Stadler W, Stadler P, Weibel F, Schumacer R. 1998. New methods of environmentally safe regulation of flower and fruit set and of alternate bearing of the apple crop. *Acta Horticultarae* 466: 65-70.

Byers RE. 1989. Response of peach trees to bloom thinning. *Acta Horticultarae* 254: 125-132.

Calvin L, Martin P. 2010. The U.S. Produce Industry and Labor: *Facing the Future in a Global Economy*. *U.S. Department of Agriculture, Economic Research Service* 106: 1-57.

Costa G, Vizzotto G. 2000. Fruit thinning of peach trees. *Plant Growth Regulation* 31: 113-119.

Crisosto CH, Johnson RS, de Jong T. 1997. Orchard factors affecting postharvest stone fruit quality. *HortScience* 32: 820-823.

Day KR, de Jong TM. 1998. Improving fruit size: Thinning and girdling nectarines, peaches, and plums. *Presented at the Curso Internacional de Fruticultura de Clima Templado-Frio in Mendoza, 16-20 June, Argentina*.

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

Dennis Jr, FG. 2000. The history of fruit thinning. *Plant Growth Regulation* 31: 1-16.

García-Pallas I, Val J, Blanco A. 2001. The inhibition of flower bud differentiation in 'Crimson Gold' nectarine with GA3 as an alternative to hand thinning. *Scientia Horticulturae* 90: 265-278.

González-Rossia D, Reig C, Juan M, Agustí M. 2007. Horticultural factors regulating effectiveness of GA_3 inhibiting flowering in peaches and nectarines (*Prunus persica* L. Batsch). *Scientia Horticulturae* 111: 352-357.

Hehnen D, Hanrahan I, Lewis K, Mcferson J, Blanke M. 2012. Mechanical flower thinning improves fruit quality of apples and promotes consistent bearing. *Scientia Horticulturae* 134: 241-244.

Kasai S, Hayama H, Kashimura Y, Kudo S, Osanai Y. 2008. Relationship between fruit cracking and expression of the gene *MdEXPA3* in 'Fuji' apples (*Malus domestica* Borkh.). *Scientia Horticulturae* 116: 194-198.

Kon MT, Schupp JR, Edwin H, Winzeler HE, Marini RP. 2013. Influence of mechanical string thinning treatments on vegetative and reproductive tissues, fruit set, yield, and fruit quality of 'Gala' apple. *HortScience* 48(1): 40-46.

Myers SC, King A, Savelle AT. 1993. Bloom thinning of 'Winblo' peach and 'Fantasia' nectarine with monocarbamide dihydrogensulfate. *HortScience* 28(6): 616-617.

Ngugi HK, Schupp JR. 2009. Evaluation of the risk of spreading fire blight in apple orchards with a mechanical string blossom thinner. *HortScience* 44(3): 862-865.

Reighard GL, Byers RE. 2009. Peach thinning. Available: www.ent.uga.edu/peach/peachhbk/cultural/thinning.pdf.

Rosa UA, Cheetancheri KG, Gliever CJ, Lee SH, Thompson J, Slaughter DC. 2008. An electro-mechanical limb shaker for fruit thinning. *Computers and electronics in agriculture* 61: 213-221.

Schupp JR, Baugher TA. 2011. Peach blossom string thinner performance improved with selective pruning. *HortScience* 46(11): 1486-1492.

Schupp JR, Baugher TA, Miller SS, Harsh RM, Lesser KM. 2008. Mechanical thinning of peach and apple trees reduces labor input and increases fruit size. *HortTechnology* 18(4): 660-670.

Seehuber C, Damegrow L, Blanke M. 2011. Regulation of source: sink relationship, fruit set, fruit growth and fruit quality in European plum (*Prunus domestica* L.)-using thinning for crop load management. *Plant Growth Regulation* 65: 335-341.

Solomakhin AA, Blanke MM. 2010. Mechanical flower thinning improves the fruit quality of apples. *Journal of Science of Food and Agriculture* 90: 735-741.

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

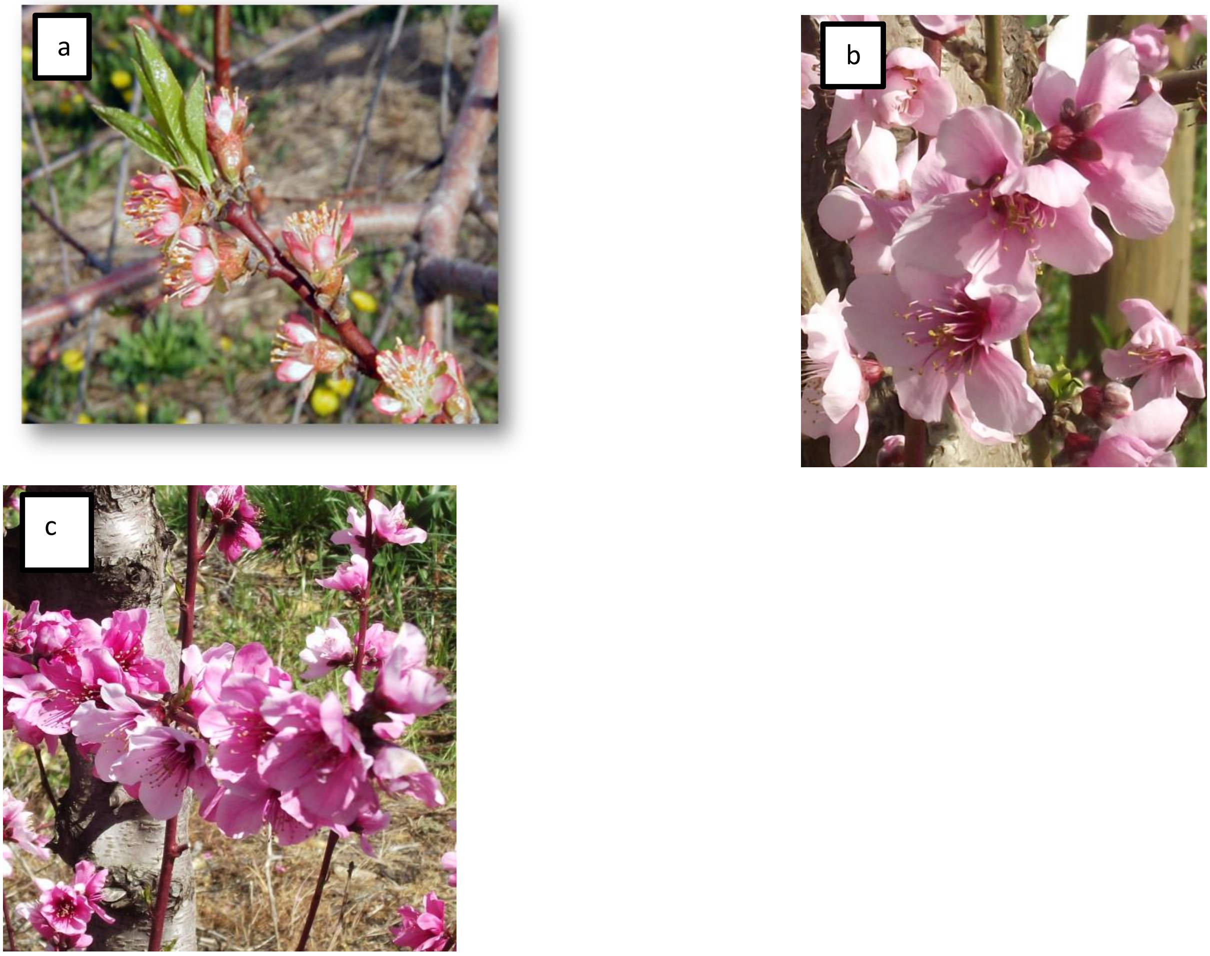

Fig. 1. (a) Non-showy flowers of ‘Summer Fire’ nectarine and showy flower of (b) ‘Royal Sun’ and (c) ‘Zephyr’. (http://www.google.com/patents/USPP7506) (http://www.clemson.edu/hort/peach/index.php?p=181&e=3519).

Table 1 a: A summary of the dates of bloom thinning, fruitlet thinning and harvest, for the cultivars Zephyr, Summer Fire and Royal Sun.

Phenological stage	2011/2012 season	2012/2013 season
	'Zephyr'	
Full bloom mechanical thinning	8 September 2011	17 September 2012
Fruitlet hand thinning	24 October 2011	1 November 2012
Harvest	30 January 2012	30 January 2013
	3 February 2012	1, 4, 6 February 2013
Winter pruning	14 June 2012	16 July 2013
	'Summer Fire'	
Full bloom mechanical thinning	8 September 2011	17 September 2012
Fruitlet hand thinning	24 October 2011	2 November 2012
Harvest	6 ,8 February of 2012	6, 8 ,12, 14 February 2013
Winter pruning	14 June 2012	16 July 2013
	'Royal Sun'	
Flower hand thinning		27 July 2012
Full bloom mechanical thinning		2 August 2012
Fruitlet hand thinning		12 September 2012
Harvest		24, 26, 27 October 2012

Table 1 b: A summary of the orchard history for the cultivars Zephyr, Summer Fire and Royal Sun.

	Previous yield (ton Ha^{-1})			
Cultivar	2008	2009	2010	2011
'Zephyr'	18	20	25	
'Summer Fire'	18	20	25	
'Royal Sun'				16

Table 2: The percentage of flowers removed at full bloom with the Darwin 300™ in 'Zephyr' and 'Summer Fire', and the effect on the resultant requirement for hand thinning and number of fruitlets removed per five-tree plot (2011/2012).

	Zephyr			Summer Fire		
	Full Bloom	Fruitlet stage		Full Bloom	Fruitlet stage	
Treatment	Percentage of flowers removed	Hand thinning time (min)	Number of fruitlets removed	Percentage of flowers removed	Hand thinning time (min)	Number of fruitlets removed
Control (only handthinned)		32.6 a	4181 a		44.8 a	3919 a
200 r.p.m.	47.2 b	22.0 b	2687 b	46.8 NS	28.0 b	2036 b
220 r.p.m.	62.3 a	18.4 bc	2456 b	57.3	34.8 ab	2275 b
240 r.p.m.	64.9 a	15.0 c	1769 c	59.1	28.0 b	1821 b
Significance level	*0.0061*	*<0.0001*	*<0.0001*	*0.0678*	*0.0340*	*0.0003*
Significance level (Linear)	*0.0012*	*0.0092*	*0.0004*	*0.0266*	*1.0000*	*0.5644*
Significance level (Quadratic)	*0.7409*	*0.9600*	*0.1885*	*0.1676*	*0.3460*	*0.7358*

NS non-significant

Table 3: The percentage of flowers removed at full bloom with the Darwin 300™, and the effect on the resultant percentage of fruit set per five-tree plot, in 'Zephyr', 'Summer Fire' and 'Royal Sun' (2012/2013).

Treatment	Zephyr		Summer Fire		Royal Sun
	Percentage of flowers removed	Percentage of fruit set	Percentage of flowers removed	Percentage of fruit set	Percentage of flowers removed
Control (Bloom thinned)					51.5 [NS]
Control (only handthinned)		83.7 [NS]		87.5 [NS]	
200 r.p.m.	62.7 [NS]	83.0	57.9 b	88.4	50.1
220 r.p.m.	61.6	84.0	65.5 a	87.4	50.1
240 r.p.m.	70.2	85.7	67.5 a	85.5	*53.0*
Significance level	*0.1090*	*0.9508*	0.0083	0.6419	*0.9809*
Significance level (Linear)	*0.0858*	*0.5873*	0.0036	0.2257	*0.7246*
Significance level (Quadratic)	*0.1868*	*0.9218*	0.2060	0.8441	*0.8381*

[NS] non-significant

Table 4: The effect of bloom thinning performed with the Darwin 300™, on the resultant time required to hand thin, and the number of fruitlets removed per five-tree plot in 'Zephyr', 'Summer Fire' and 'Royal Sun' (2012/2013).

	Zephyr		Summer Fire		Royal Sun	
	Fruitlet stage		Fruitlet stage		Fruitlet stage	
Treatment	Hand thinning time (min)	Number of fruitlets removed	Hand thinning time (min)	Number of fruitlets removed	Hand thinning time (min)	Number of fruitlets removed
Control (hand bloom thinned)					17.4 a	4394 b
Control (only handthinned)	16.4 a	3205 a	14.4 a	3176 a	19.1 a	6651 a
200 r.p.m.	10.4 b	1528 b	10.2 b	1672 b	12.1 b	3700 b
220 r.p.m.	12.6 ab	1718 b	9.4 b	1353 b	12.8 b	3535 b
240 r.p.m.	10.0 b	1439 b	8.6 b	1360 b	13.0 b	3990 b
Significance level	*0.0213*	*0.0014*	<0.0001	<0.0001	*<0.0001*	*0.0006*
Significance level (Linear)	*0.8375*	*0.8157*	0.0806	0.0825	*0.5558*	*0.6789*
Significance level (Quadratic)	*0.1722*	*0.4797*	1.0000	0.2747	*0.8838*	*0.6103*

NS non-significant

Table 5: The effect of thinning at full bloom with the Darwin 300™, on the yield per cross sectional trunk tree area in 'Zephyr' (2011/2012).

Treatment	Yield per tree(kg.cm^{-2}) at first harvest and percentage of harvest			Yield per tree(kg.cm^{-2}) at second harvest and percentage of harvest			Total yield per tree (kg.cm^{-2})		Yield (ton.ha^{-1})
	kg.cm^{-2}		%	kg.cm^{-2}		%			
Control (only handthinned)	0.24	a	(31.6)	0.51	a	(68.4)	0.75	a	24
200 r.p.m.	0.23	ab	(33.4)	0.45	ab	(66.7)	0.68	a	22
220 r.p.m.	0.18	bc	(31.6)	0.38	b	(68.4)	0.56	b	21
240 r.p.m.	0.14	c	(25.9)	0.41	b	(74.1)	0.55	b	20
Significance level	*0.0136*			0.0311			0.0009		.
Significance level (Linear)	*0.0092*			*0.3262*			*0.0109*		.
Significance level (Quadratic)	*0.7809*			*0.1728*			*0.1375*		.

^{NS} non-significant

Table 6: The effect of thinning at full bloom with the Darwin 300™, on the yield per cross sectional trunk tree area in 'Summer Fire' (2011/2012).

Treatment	Yield per tree ($kg.cm^{-2}$) at first harvest and percentage of harvest		Yield per tree ($kg.cm^{-2}$) at second harvest and percentage of harvest		Total yield per tree ($kg.cm^{-2}$)	Yield ($ton.ha^{-1}$)
	$kg.cm^{-2}$	%	$kg.cm^{-2}$	%		
Control (only handthinned)	0.42 NS	(79.2)	0.18 NS	(20.8)	0.60 NS	32
200 r.p.m.	0.28	(76.9)	0.10	(23.1)	0.38	29
220 r.p.m.	0.30	(76.3)	0.11	(23.7)	0.41	33
240 r.p.m.	0.22	(77.8)	0.09	(22.2)	0.31	24
Significance level	*0.0989*		*0.8087*		*0.2707*	.
Significance level (Linear)	*0.1254*		*0.6604*		*0.2311*	.
Significance level (Quadratic)	*0.1710*		*0.5680*		*0.2347*	.

NS non-significant

Table 7: The effect of thinning at full bloom with the Darwin 300™, on the yield per cross sectional trunk tree area in 'Zephyr' (2012/2013).

Treatment	Yield per tree ($kg.cm^{-2}$) at first harvest and percentage of harvest			Yield per tree ($kg.cm^{-2}$) at second harvest and percentage of harvest		Yield per tree ($kg.cm^{-2}$) at third harvest and percentage of harvest		Yield per tree ($kg.cm^{-2}$) at fourth harvest and percentage of harvest		Total yield per tree ($kg.cm^{-2}$)		Yield ($ton.ha^{-1}$)
	$kg.cm^{-2}$		%	$kg.cm^{-2}$	%	$kg.cm^{-2}$	%	$kg.cm^{-2}$	%			
Control (only handthinned)	0.16	a	(20.2)	0.21 NS	(27.1)	0.14 NS	(17.3)	0.28 NS	(35.4)	0.78	a	47
200 r.p.m.	0.10	b	(17.1)	0.14	(22.7)	0.12	(19.1)	0.25	(41.0)	0.61	ab	39
220 r.p.m.	0.10	b	(16.5)	0.17	(28.9)	0.11	(17.7)	0.22	(37.0)	0.60	b	43
240 r.p.m.	0.09	b	(16.7)	0.13	(23.8)	0.10	(19.5)	0.20	(40.0)	0.51	b	39
Significance level	*0.0026*			*0.0533*		*0.3549*		*0.3919*		*0.0414*		.
Significance level (Linear)	*0.3429*			*0.6384*		*0.3968*		*0.3865*		*0.2591*		.
Significance level (Quadratic)	*0.9656*			*0.1130*		*0.9457*		*0.3919*		*0.5726*		.

NS non-significant

Table 8: The effect of thinning at full bloom with the Darwin 300™, on the yield per cross sectional trunk tree area in 'Summer Fire' (2012/2013).

Treatment	Yield per tree ($kg.cm^{-2}$) at first harvest and percentage of harvest		Yield per tree ($kg.cm^{-2}$) at second harvest and percentage of harvest		Yield per tree ($kg.cm^{-2}$) at third harvest and percentage of harvest		Yield per tree ($kg.cm^{-2}$) at fourth harvest and percentage of harvest		Total yield per tree ($kg.cm^{-2}$)	Yield ($ton.ha^{-1}$)
	$kg.cm^{-2}$	%	$kg.cm^{-2}$	%	$kg.cm^{-2}$	%	$kg.cm^{-2}$	%		
Control (only handthinned)	0.14 NS	(25.3)	0.11 NS	(20.3)	0.12 NS	(21.6)	0.18 a	(32.9)	0.55 a	48
200 r.p.m.	0.15	(35.1)	0.07	(15.5)	0.08	(18.5)	0.14 ab	(30.9)	0.43 b	39
220 r.p.m.	0.17	(41.1)	0.09	(22.4)	0.07	(18.0)	0.08 b	(18.5)	0.42 b	37
240 r.p.m.	0.11	(28.2)	0.09	(24.7)	0.07	(21.1)	0.10 b	(26.0)	0.37 b	34
Significance level	*0.3863*		*0.2452*		*0.0609*		*0.0196*		*0.0254*	.
Significance level (Linear)	*0.2941*		*0.2264*		*0.6558*		*0.1867*		*0.2466*	.
Significance level (Quadratic)	*0.1731*		*0.4287*		*0.6894*		*0.1317*		*0.7421*	.

NS non-significant

Table 9: The effect of thinning with the Darwin 300™ on yield per cross sectional trunk tree area in 'Royal Sun' (2012/2013).

Treatment	Yield per tree ($kg.cm^{-2}$) at first harvest and percentage of harvest		Yield per tree ($kg.cm^{-2}$) at second harvest and percentage of harvest		Yield per tree ($kg.cm^{-2}$) at third harvest and percentage of harvest		Total yield per tree ($kg.cm^{-2}$)	Yield ($ton.ha^{-1}$)
	$kg.cm^{-2}$	%	$kg.cm^{-2}$	%	$kg.cm^{-2}$	%		
Control (only handthinned)	0.07 NS	(37.0)	0.04 NS	(19.2)	0.08 a	(43.8)	0.19 a	19
Control (Bloom thinned)	0.08	(46.2)	0.03	(19.4)	0.06 b	(34.3)	0.17 ab	18
200 r.p.m.	0.07	(46.2)	0.03	(20.5)	0.05 b	(33.3)	0.15 bc	17
220 r.p.m.	0.06	(43.4)	0.03	(18.5)	0.06 b	(38.1)	0.15 c	16
240 r.p.m.	0.07	(43.8)	0.03	(19.2)	0.06 b	(37.0)	0.16 bc	17
Significance level	*0.3254*		*0.4074*		*<0.0001*		*0.0177*	.
Significance level (Linear)	*0.8043*		*0.7098*		*0.2213*		*0.8012*	.
Significance level (Quadratic)	*0.3809*		*0.4004*		*0.8231*		*0.4650*	.

NS non-significant

Table 10: The effect of thinning with the Darwin 300^{TM} at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the first harvest of 'Zephyr' (2011/2012).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	184.4 c	11.111 a	68.3 c	68.2 c	12.32 ^{NS}	32 ^{NS}	0 ^{NS}
200 r.p.m.	209.5 b	9.418 b	70.6 b	71.6 b	12.64	38	1
220 r.p.m.	223.4 ab	9.474 b	72.8 a	73.7 a	13.64	37	1
240 r.p.m.	226.8 a	11.560 a	73.7 a	74.4 a	13.64	35	1
Significance level	*0.0003*	*0.0155*	*0.0005*	*<.0001*	*0.0593*	*0.8672*	*0.8338*
Significance level (Linear)	*0.0362*	*0.0090*	*0.0073*	*0.0083*	*0.0858*	*0.6667*	*0.9501*
Significance level (Quadratic)	*0.4196*	*0.1148*	*0.4319*	*0.3808*	*0.3010*	*0.9822*	*0.9712*

^{NS} non-significant; * Total soluble solids concentration

Table 11: The effect of thinning with the Darwin 300^{TM} at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the second harvest of 'Zephyr' (2011/2012).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	185.2 c	11.181 ^{NS}	69.3 b	69.0 C	11.54 ^{NS}	2 ^{NS}	0 ^{NS}
200 r.p.m.	217.5 b	11.291	73.7 a	73.3 B	11.14	3	0
220 r.p.m.	221.8 ab	12.060	73.7 a	73.9 Ab	11.04	4	0
240 r.p.m.	232.4 a	11.847	74.9 a	75.3 A	11.58	3	1
Significance level	*<.0001*	*0.0621*	*<.0001*	*<.0001*	*0.1322*	*0.9480*	*0.4262*
Significance level (Linear)	*0.0325*	*0.1245*	*0.1444*	*0.0271*	*0.1136*	*1.0000*	*0.1827*
Significance level (Quadratic)	*0.5712*	*0.1176*	*0.4078*	*0.5649*	*0.1773*	*0.7375*	*0.4301*

^{NS} non-significant; * Total soluble solids concentration

Table 12: The effect of thinning with the Darwin 300^{TM} at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the combined data of 'Zephyr' (2011/2012).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	185.4 c	11.107 bc	69.0 c	68.8 c	11.80 ^{NS}	11 ^{NS}	0 ^{NS}
200 r.p.m.	215.0 b	10.665 c	72.7 b	72.8 b	11.63	15	0
220 r.p.m.	222.5 ab	11.249 ab	73.4 ab	73.8 ab	11.85	14	0
240 r.p.m.	231.4 a	11.785 a	74.7 a	75.1 a	12.09	12	1
Significance level	*<0.0001*	*0.0091*	*<0.0001*	*<0.0001*	*0.4634*	*0.7121*	*0.5128*
Significance level (Linear)	*0.0084*	*0.0011*	*0.0201*	*0.0057*	*0.1271*	*0.3991*	*0.3738*
Significance level (Quadratic)	*0.8726*	*0.9178*	*0.7136*	*0.8650*	*0.9529*	*0.7296*	*0.4788*

^{NS} non-significant; * Total soluble solids concentration

Table 13: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the first harvest of 'Summer Fire' (2011/2012).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	192.4 NS	13.46 NS	68.8 NS	70.1 NS	15.64 NS	1 NS	5 a
200 r.p.m.	214.4	14.25	71.5	72.6	15.42	0	1 b
220 r.p.m.	217.2	13.21	71.1	72.9	14.58	0	2 ab
240 r.p.m.	219.0	13.48	71.5	73.2	14.94	0	0 b
Significance level	*0.0717*	*0.5572*	*0.1399*	*0.1130*	*0.6685*	*0.4505*	*0.0244*
Significance level (Linear)	*0.6520*	*0.2706*	*0.9598*	*0.6369*	*0.5694*	*1.0000*	*0.5732*
Significance level (Quadratic)	*0.7482*	*0.4641*	*0.8109*	*0.7796*	*0.5128*	*0.9080*	*0.1996*

NS non-significant; * Total soluble solids concentration

Table 14: The effect of thinning with the Darwin 300^{TM} at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the second harvest of 'Summer Fire' (2011/2012).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	182.2 ^{NS}	12.55 ^{NS}	68.6 ^{NS}	69.0 ^{NS}	13.15 ^{NS}	0 ^{NS}	0 ^{NS}
200 r.p.m.	192.9	11.81	69.2	70.3	13.48	1	0
220 r.p.m.	176.6	11.10	67.7	68.7	11.03	0	7
240 r.p.m.	194.7	11.92	69.1	70.2	13.42	0	5
Significance level	*0.3086*	*0.5909*	*0.6569*	*0.6061*	*0.0917*	*0.4805*	*0.6370*
Significance level (Linear)	*0.8397*	*0.9052*	*0.8941*	*0.9484*	*0.9528*	*0.2230*	*0.3687*
Significance level (Quadratic)	*0.1105*	*0.3791*	*0.2461*	*0.3145*	*0.0171*	*0.4521*	*0.4270*

^{NS} non-significant; * Total soluble solids concentration

Table 15: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the combined data of 'Summer Fire' (2011/2012).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	190.3 NS	13.363 NS	68.8 NS	69.8 NS	15.12 NS	1 NS	4 a
200 r.p.m.	210.9	13.865	71.1	72.2	14.90	0	1 b
220 r.p.m.	211.7	12.839	70.7	72.4	13.76	0	2 ab
240 r.p.m.	215.7	13.151	71.2	72.9	14.52	0	0 b
Significance level	*0.0956*	*0.5921*	*0.1791*	*0.1262*	*0.4573*	*0.5468*	*0.0343*
Significance level (Linear)	*0.6389*	*0.2976*	*0.9514*	*0.6276*	*0.6507*	*0.6842*	*0.8464*
Significance level (Quadratic)	*0.9400*	*0.3925*	*0.8209*	*0.9014*	*0.2336*	*0.7225*	*0.2524*

NS non-significant; * Total soluble solids concentration

Table 16: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the first harvest of 'Zephyr' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	242.7 NS	10.506 NS	74.6 NS	77.5 NS	13.52 c	11 NS	13 b
200 r.p.m.	251.5	10.814	73.6	78.7	15.58 b	24	43 a
220 r.p.m.	256.5	10.315	74.6	79.3	17.22 a	28	47 a
240 r.p.m.	263.7	11.399	74.6	80.0	16.02 ab	14	16 b
Significance level	*0.2912*	*0.5366*	*0.7828*	*0.2384*	*0.0008*	*0.0698*	*0.0125*
Significance level (Linear)	*0.2715*	*0.4609*	*0.3965*	*0.2760*	*0.5086*	*0.1592*	*0.0254*
Significance level (Quadratic)	*0.9081*	*0.2569*	*0.6649*	*0.9482*	*0.0260*	*0.1381*	*0.0796*

NS non-significant; * Total soluble solids concentration

Table 17: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the second harvest of 'Zephyr' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	238.9 NS	11.149 NS	74.4 NS	77.3 NS	12.92 b	10 NS	8 NS
200 r.p.m.	262.2	12.911	75.6	79.9	15.76 a	24	23
220 r.p.m.	262.4	11.678	75.3	80.1	15.94 a	22	25
240 r.p.m.	260.9	11.754	75.4	80.0	13.92 b	15	19
Significance level	*0.3084*	*0.0825*	*0.7716*	*0.3765*	*0.0007*	*0.0547*	*0.1656*
Significance level (Linear)	*0.9269*	*0.0879*	*0.8478*	*0.9459*	*0.0104*	*0.0993*	*0.6079*
Significance level (Quadratic)	*0.9475*	*0.2480*	*0.8034*	*0.9540*	*0.0582*	*0.7370*	*0.4914*

NS non-significant; * Total soluble solids concentration

Table 18: The effect of thinning with the Darwin 300TM at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the third harvest of 'Zephyr' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	235.3 b	10.864 NS	74.1 NS	76.9 B	12.14 NS	7 NS	4 NS
200 r.p.m.	260.3 a	11.729	75.6	80.1 A	13.34	8	20
220 r.p.m.	260.9 a	11.294	75.9	80.0 A	12.84	6	8
240 r.p.m.	266.4 a	12.053	75.7	80.7 A	13.26	11	8
Significance level	*0.0388*	*0.3798*	*0.1791*	*0.0437*	*0.3142*	*0.8761*	*0.1852*
Significance level (Linear)	*0.5541*	*0.6482*	*0.9397*	*0.6528*	*0.9078*	*0.6439*	*0.1181*
Significance level (Quadratic)	*0.7818*	*0.3391*	*0.7479*	*0.7370*	*0.4475*	*0.5442*	*0.3503*

NS non-significant; * Total soluble solids concentration

Table 19: The effect of thinning with the Darwin 300^{TM} at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the fourth harvest of 'Zephyr' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	216.1 ^{NS}	11.527 ^{NS}	73.0 ^{NS}	74.7 ^{NS}	11.60 ^{NS}	0 c	3 ^{NS}
200 r.p.m.	246.7	12.783	74.8	78.4	13.06	10 a	5
220 r.p.m.	250.9	11.941	74.8	78.7	13.42	8 ab	5
240 r.p.m.	255.4	12.253	74.9	79.5	12.78	5 b	5
Significance level	*0.0543*	*0.3529*	*0.4158*	*0.0661*	*0.2332*	*0.0014*	*0.7914*
Significance level (Linear)	*0.5383*	*0.4539*	*0.9020*	*0.5179*	*0.7535*	*0.0260*	*1.0000*
Significance level (Quadratic)	*0.9873*	*0.3499*	*0.9628*	*0.8413*	*0.5201*	*0.6339*	*1.0000*

^{NS} non-significant; * Total soluble solids concentration

Table 20: The effect of thinning with the Darwin 300^{TM} at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the combined data of 'Zephyr' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	231.4 NS	11.117 NS	74.0 NS	76.4 NS	12.42 c	6 c	7 NS
200 r.p.m.	253.6	12.314	74.9	79.1	14.21 ab	15 a	19
220 r.p.m.	256.5	11.455	75.2	79.4	14.62 a	14 ab	19
240 r.p.m.	259.7	11.919	75.2	79.9	13.70 b	10 bc	11
Significance level	*0.0628*	*0.1694*	*0.5245*	*0.0749*	*0.0011*	*0.0056*	*0.0850*
Significance level (Linear)	*0.5575*	*0.4678*	*0.7544*	*0.5437*	*0.2405*	*0.0369*	*0.1254*
Significance level (Quadratic)	*0.9914*	*0.1718*	*0.8716*	*0.9137*	*0.0904*	*0.3552*	*0.4287*

NS non-significant; * Total soluble solids concentration

Table 21: The effect of thinning with the Darwin 300^{TM} at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the first harvest of 'Summer Fire' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	197.8 ^{NS}	12.640 ^{NS}	68.7 ^{NS}	71.8 ^{NS}	17.12 ^{NS}	6 ^{NS}	9 ^{NS}
200 r.p.m.	195.5	14.276	68.4	71.5	17.12	2	8
220 r.p.m.	189.6	14.033	68.1	70.7	17.34	1	8
240 r.p.m.	194.6	12.936	68.2	71.4	18.04	5	7
Significance level	*0.5400*	*0.3580*	*0.8748*	*0.4765*	*0.6931*	*0.3020*	*0.9637*
Significance level (Linear)	*0.8705*	*0.2245*	*0.8535*	*0.8825*	*0.3148*	*0.2845*	*0.7984*
Significance level (Quadratic)	*0.2830*	*0.6464*	*0.7446*	*0.2516*	*0.7574*	*0.3511*	*0.8827*

^{NS} non-significant; * Total soluble solids concentration

Table 22: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the second harvest of 'Summer Fire' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	198.2 NS	12.450 NS	69.3 NS	72.2 NS	14.88 NS	2 NS	4 NS
200 r.p.m.	201.8	12.734	69.7	72.5	15.98	1	8
220 r.p.m.	198.1	12.297	69.1	72.4	14.14	2	7
240 r.p.m.	202.6	12.693	69.0	72.7	15.76	1	3
Significance level	*0.8151*	*0.8792*	*0.8638*	*0.9179*	*0.1258*	*0.4262*	*0.4967*
Significance level (Linear)	*0.8861*	*0.9483*	*0.4480*	*0.7715*	*0.7837*	*1.0000*	*0.1806*
Significance level (Quadratic)	*0.4439*	*0.4530*	*0.7377*	*0.7126*	*0.0255*	*0.1138*	*0.6888*

NS non-significant; * Total soluble solids concentration

Table 23: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the third harvest of 'Summer Fire' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	205.6 NS	10.197 ab	70.3 NS	73.4 NS	13.36 NS	0 NS	0 NS
200 r.p.m.	203.8	9.659 b	70.1	73.0	12.66	1	4
220 r.p.m.	209.1	10.946 a	70.4	73.8	13.82	6	1
240 r.p.m.	214.0	9.936 b	70.9	74.4	13.30	0	1
Significance level	*0.3519*	*0.0240*	*0.8101*	*0.2161*	*0.6774*	*0.4262*	*0.4771*
Significance level (Linear)	*0.1037*	*0.4656*	*0.3616*	*0.0531*	*0.5075*	*0.8372*	*0.3115*
Significance level (Quadratic)	*0.9709*	*0.0036*	*0.9475*	*0.8663*	*0.3209*	*0.1409*	*0.5532*

NS non-significant; * Total soluble solids concentration

Table 24: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the fourth harvest of 'Summer Fire' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	194.1 ^{NS}	9.677 ^{NS}	69.1 ^{NS}	71.9 ^{NS}	11.84 ^{NS}	0	3 ^{NS}
200 r.p.m.	182.4	10.383	67.5	69.6	12.20	0	1
220 r.p.m.	199.0	10.312	69.4	72.4	12.56	0	1
240 r.p.m.	199.3	8.954	69.7	72.6	12.08	0	0
Significance level	*0.2494*	*0.3023*	*0.3358*	*0.2194*	*0.4434*		*0.6181*
Significance level (Linear)	*0.0830*	*0.1023*	*0.1038*	*0.0679*	*0.7865*		*0.5098*
Significance level (Quadratic)	*0.3132*	*0.3753*	*0.4527*	*0.3385*	*0.2848*		*0.7018*

^{NS} non-significant; * Total soluble solids concentration

Table 25: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, percentage cracked fruit and percentage split pit at the combined data of 'Summer Fire' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of cracked fruit	Percentage of split pit
Control (only handthinned)	198.7 ^{NS}	11.064 ^{NS}	69.3 ^{NS}	72.3 ^{NS}	14.06 ^{NS}	1 ^{NS}	3 ^{NS}
200 r.p.m.	195.3	11.912	68.9	71.7	14.61	1	5
220 r.p.m.	196.7	12.324	69.0	72.0	15.05	1	5
240 r.p.m.	202.6	11.331	69.4	72.8	14.96	2	3
Significance level	*0.5573*	*0.1594*	*0.8434*	*0.4499*	*0.3611*	*0.6727*	*0.3763*
Significance level (Linear)	*0.1921*	*0.3201*	*0.4374*	*0.1398*	*0.5588*	*0.2768*	*0.2018*
Significance level (Quadratic)	*0.6294*	*0.1729*	*0.8087*	*0.6438*	*0.6048*	*0.6257*	*0.3486*

^{NS} non-significant; * Total soluble solids concentration

Table 26: The effect of thinning with the Darwin 300^{TM} at full bloom on fruit weight, firmness, length, fruit diameter, TSS, and percentage split pit at the first harvest of 'Royal Sun' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of fruit with split pit
Control (only handthinned)	103.1 ^{NS}	9.445 ^{NS}	57.0 ^{NS}	59.0 ^{NS}	8.53 ^{NS}	99 ^{NS}
Control (Bloom thinned)	110.1	8.960	56.8	60.6	8.51	100
200 r.p.m.	104.3	10.069	56.6	59.3	8.64	100
220 r.p.m.	105.7	10.111	56.3	59.5	7.50	95
240 r.p.m.	104.6	9.646	56.3	59.5	8.54	100
Significance level	*0.1191*	*0.1864*	*0.3846*	*0.0623*	*0.4814*	*0.4726*
Significance level (Linear)	*0.8975*	*0.4247*	*0.5048*	*0.8032*	*0.8888*	*1.000*
Significance level (Quadratic)	*0.5911*	*0.5790*	*0.5684*	*0.8568*	*0.0874*	*0.0842*

^{NS} non-significant; * Total soluble solids concentration

Table 27: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, and percentage split pit at the second harvest of 'Royal Sun' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of fruit with split pit
Control (only handthinned)	92.4 c	10.319 NS	56.3 NS	56.7 C	8.35 NS	100 NS
Control (Bloom thinned)	95.8 bc	9.627	56.3	59.5 B	8.23	100
200 r.p.m.	97.8 ab	9.817	56.6	60.0 B	8.84	100
220 r.p.m.	97.9 ab	10.299	56.8	60.2 Ab	8.43	100
240 r.p.m.	99.2 a	9.693	57.0	60.8 A	8.63	100
Significance level	*0.0033*	*0.1973*	*0.3846*	*<0.0001*	*0.1920*	
Significance level (Linear)	*0.4329*	*0.7406*	*0.7057*	*0.0406*	*0.4320*	
Significance level (Quadratic)	*0.6765*	*0.1018*	*0.3999*	*0.4529*	*0.1953*	

NS non-significant; * Total soluble solids concentration

Table 28: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, and percentage split pit at the third harvest of 'Royal Sun' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of fruit with split pit
Control (only handthinned)	80.5 NS	10.259 NS	54.0 NS	55.5 NS	7.80 NS	100 NS
Control (Bloom thinned)	82.0	10.176	53.8	55.7	8.09	100
200 r.p.m.	82.9	9.775	53.6	56.2	8.34	100
220 r.p.m.	83.6	10.310	54.6	56.2	8.21	100
240 r.p.m.	82.5	10.267	54.1	56.1	8.30	100
Significance level	*0.5841*	*0.5162*	*0.3684*	*0.4911*	*0.1594*	
Significance level (Linear)	*0.8406*	*0.1592*	*0.3429*	*0.8741*	*0.8713*	
Significance level (Quadratic)	*0.5930*	*0.3337*	*0.0888*	*0.7991*	*0.5968*	

NS non-significant; * Total soluble solids concentration

Table 29: The effect of thinning with the Darwin 300™ at full bloom on fruit weight, firmness, length, fruit diameter, TSS, and percentage split pit at the combined data of 'Royal Sun' (2012/2013).

Treatment	Fruit weight (g)	Fruit firmness (kg)	Fruit length (mm)	Fruit diameter (mm)	TSS (%)*	Percentage of fruit with split pit
Control (only handthinned)	91.2 b	9.962 NS	55.5 NS	57.0 B	8.17 NS	100 NS
Control (Bloom thinned)	97.9 a	9.480	55.7	58.7 A	8.29	100
200 r.p.m.	96.0 a	9.862	55.6	58.4 A	8.57	100
220 r.p.m.	95.7 a	10.191	55.8	58.3 A	7.93	98
240 r.p.m.	95.6 a	9.899	55.7	58.5 A	8.47	100
Significance level	*0.0095*	*0.3729*	*0.9190*	*0.0005*	*0.4055*	*0.4631*
Significance level (Linear)	*0.8019*	*0.9159*	*0.6987*	*0.8148*	*0.7869*	*1.000*
Significance level (Quadratic)	*0.9076*	*0.3085*	*0.6077*	*0.6280*	*0.0616*	*0.0824*

NS non-significant; * Total soluble solids concentration

Table 30: The effect bloom thinning with the Darwin 300™ on the weight of prunings removed and the tree volume, in 'Zephyr' and 'Summer Fire' trees the following winter (2011/2012).

Treatment	Zephyr		Summer Fire	
	Weight of prunings (kg)	Tree volume (m^3)	Weight of prunings (kg)	Tree volume (m^3)
Control (only handthinned)	8.5 b	2.844 NS	13.2 NS	4.3 NS
200 r.p.m.	10.7 ab	2.825	12.8	4.2
220 r.p.m.	11.8 a	3.199	14.6	4.2
240 r.p.m.	13.4 a	3.130	16.1	4.8
Significance level	*0.0251*	*0.0786*	*0.3356*	*0.1769*
Significance level (Linear)	*0.0714*	*0.0810*	*0.1031*	*0.0726*
Significance level (Quadratic)	*0.8270*	*0.1353*	*0.9485*	*0.3395*

NS non-significant

Table 31: The effect bloom thinning with the Darwin 300[TM] on the weight of prunings removed and the tree volume, in 'Zephyr' and 'Summer Fire' trees the following winter (2012/2013).

Treatment	Zephyr		Summer Fire	
	Weight of prunings (kg)	Tree volume (m^3)	Weight of prunings (kg)	Tree volume (m^3)
Control (only handthinned)	13.0 [NS]	3.695 [NS]	13.910 [NS]	5.282 [NS]
200 r.p.m.	13.8	3.752	15.040	4.983
220 r.p.m.	15.1	3.949	14.262	5.328
240 r.p.m.	13.3	3.973	17.084	5.216
Significance level	*0.8264*	*0.7566*	0.1249	0.7265
Significance level (Linear)	*0.8396*	*0.4922*	0.1456	0.4875
Significance level (Quadratic)	*0.4798*	*0.7561*	0.1395	0.4336

[NS] non-significant

PAPER 2: EFFICACY OF MECHANICAL THINNING IN REDUCING HAND THINNING WHILE MAINTAINING FRUIT QUALITY IN JAPANESE PLUMS

Abstract

Plum trees often set a higher number of flowers than is required for an optimal crop load, of high quality fruit of the correct size. Thinning is therefore of high importance to obtain the optimal number of fruit per tree and is mostly performed manually because chemical thinning is erratic. Hand thinning contributes to a large portion of production cost because it is labour intensive. Labour costs are also increasing and there is a shortage of labour in certain production areas. The trial was performed at the Welgevallen research farm, in Stellenbosch, South Africa, during the 2011/2012 season on the cultivar Laetitia grafted to 'Marianna' rootstock and planted in 1998 at a spacing of 4.5 x 1.5 m. Trees are trained to a hedge. During the 2012/2013 season, trials were performed on the cultivar African Rose on the farm Klein-Simonsvlei and on African Delight on the farm Babylonstoren, both farms in Simondium, South Africa. The 'African Rose' trees on 'Marianna' rootstock were planted in 2009 at a spacing of 4 x 1.5 m while the 'African Delight' trees on 'SAPO 778' rootstock were planted in 2009 at a spacing of 4 x 1.5 m. Both these orchards are trained to a 7-wire hedge system (hedge). For both seasons, the Darwin 300™ was used at a consistent tractor speed of 4.8 km h^{-1}, while the mechanical thinning was performed at full bloom with rotor speeds of 250, 280 and 310 r.p.m. for the 'African Delight' and 220, 250 and 280 r.p.m. for 'Laetitia' and 'African Rose'. A randomised complete block design was used for all the trials with 3 blocks and 7 trees per plot (using central 3 trees for data collection) for 'Laetitia', 10 blocks and 7 trees per plot (using the central 5) for 'African Rose' and 10 blocks and 7 trees per plot for 'African Delight'. The time required to hand thin the three-tree plot was not significantly reduced in the case of 'Laetitia' for the 2011/2012 season, although the number of fruitlets removed showed an average reduction of 42% for the three-tree-plot. For 'African Rose' and 'African Delight' the time required to hand thin the five-tree-plots was reduced by 25% and 45%, respectively. The yield efficiency per tree was not significantly reduced in 'Laetitia' and 'African Rose', but an average reduction of 55% was found for 'African Delight'. Bloom thinning significantly increased fruit sizes in 'Laetitia' and 'African Rose', but not in 'African Delight' despite the decrease in yield efficiency. There were no negative effects found on the fruit quality for the 'Laetitia' and 'African Rose'. Fruit quality in 'African Delight' was negatively affected through a significant increase in the percentage of cracked fruit, with the 280 and 310 r.p.m. treatments increasing the percentage of cracked fruit by 12 and 13.5%, respectively. The consistent reduction in the time required for hand thinning will result in the reduction in the cost associated with hand

thinning and therefore production while the increase in fruit size could increase the marketable yield. This potential increase in income together with the reduction in cost associated with hand thinning and production could result in increases in profit. The reduction in yield might be avoided by increasing the number of fruit left on the tree after thinning, if the increase in fruit size is not wanted. The increase in fruit size could also compensate for the reduction in yield. The increase in the cracked fruit could be a direct result of the reduction in the yield per tree, therefore if more fruit were left after thinning, this effect might be avoided.

Keywords: *Prunus salicina* Lindle., fruit size, labour cost, Darwin 300™

Introduction

Most mechanical thinning trials have focused on apples or peaches rather than on plums (Webster and Spencer 2000), but plum growers are faced with a similar challenge to produce fruit of high quality and the desired size (Reighard and Byers 2009). Fruit and/or flower thinning is therefore an important practise to facilitate the production of an optimal crop of large and good quality fruit while maintaining good return bloom. 80% of the variance in final fruit size can be explained by variation in initial fruit set (González-Rossia et al. 2007). Nectarine, peach and plum trees often set more flowers than is optimal (Webster and Spencer 2000, Rosa et al. 2008). However, it should be remembered that determining the optimal crop load, thus the number of fruit after thinning, is dependent on the market price for larger fruit, the potential of the tree to achieve larger fruit sizes and higher yields, and the effect of different cultivation methods on the growth of the fruit (Byers 1989, Reighard and Byers 2009).

The use of labour to thin flowers during bloom is costly therefore it is not an economically viable option in many production regions (Webster and Spencer 2000). Thinning in stone fruit is therefore still currently done 40-60 days after full bloom (dafb) by hand and contributes largely to production costs (Rosa et al. 2008). The reason for this is that hand thinning is labour intensive (Baugher et al. 2009), labour costs are increasing (Costa and Vizzotto 2000), a shortage of labour occurs in certain production regions (Damegrow and Blanke 2009) and labour is often unproductive (Baugher et al. 2009). While hand thinning is effective in reducing the number of flowers or fruitlets, between 100 and 500 hours of labour per hectare are required, depending on the trees size and flower density, fruit set, and thinning intensity required (González-Rossia et al. 2007).

Unwanted fruit should be removed as early as possible by utilising the most cost effective method possible (Reighard and Byers 2009). Thus, the longer unwanted fruit are on the tree the bigger the adverse effect on fruit size (Reighard and Byers 2009). In addition, consumers demand that more environmentally friendly production techniques are utilised.

Mechanical thinning is a more reliable than chemical thinning and is therefore an alternative in stone fruit (Miller et al. 2011) as it reduces the number of hours needed to thin by hand (Paper 1, Baugher et al. 2008, Solomakhin and Blanke 2010, Hehnen et al. 2012). Plums flower earlier in the season than pome fruit, and the weather conditions in this period could be unfavourable for the activity of honey bees, that are very important for pollination and fruit set (Webster and Spencer 2000). This could hamper the use of mechanical bloom thinners, but if conditions are favourable during bloom the fruit set could be excessive (Webster and Spencer 2000). Mechanical thinning however does not replace hand thinning completely with skilled labour still being required at a lower level (Schupp et al. 2008). Hand thinning would therefore not be replaced entirely, but only be used for high value cultivars, or with trees which have low to medium fruit size potential (Reighard and Byers 2009).

In this paper we report on the efficacy of the Darwin 300™ string thinner at full bloom in reducing hand thinning requirement in Japanese plum orchards while also evaluating the effect on yield and fruit quality.

Materials and methods

Plant material and site description

During 2011/2012, a trial was performed on the Welgevallen research farm (33°56’50.49”S; 18°52’16.60”E), in Stellenbosch, South Africa on ‘Laetitia’ trees on ‘Marianna’ rootstock planted in 1998 at a spacing of 4.5 x 1.5 m and trained to a hedge. During 2012/2013, ‘African Rose’ on the farm Klein-Simonsvlei (33°48’29.85”S; 18°55’03.82”E) and ‘African Delight’ on the farm Babylonstoren (33°49’19.67”S; 18°55’19.50”E), both in Simondium, South Africa were used. The ‘African Rose’ trees on ‘Mariana’ rootstock were planted in 2009 at a spacing of 4 x 1.5 m. The ‘African Delight’ trees on ‘SAPO 778’ rootstock were planted in 2009 at a spacing of 4 x 1.5 m. Both these orchards are trained to a 7-wire hedge system. Additional orchard information is summarized in Table 1.

Treatments and experimental design

A hand thinned control was used in all trials and compared to mechanical thinning performed with the Darwin 300™ at full bloom at rotor speeds of 220, 250 and 280 r.p.m. in 'Laetitia' and 'African Rose', and 250, 280 and 310 r.p.m. in 'African Delight'. Tractor speed was kept constant at 4.8 km $.h^{-1}$. Details on time of machine thinning, hand thinning and harvest are summarised in Table 2.

Randomized complete block designs with three replicates for 'Laetitia' and 10 replicates for 'African Rose' were used. For 'Laetitia' each replicate consisted of a seven-tree plot of which the middle three trees were used to record data. For 'African Rose' each replicate consisted of seven trees of which the middle five were used to record data. For 'African Delight' eight replicates were used with each replicate consisting of eight trees of which the middle five were used to record data.

Data collection

For 'Laetitia', 'African Rose' and 'African Delight', the efficacy of thinning was determined by recording the time required to complete hand thinning per plot as well as the number of fruitlets thinned during commercial thinning at 20 mm diameter fruitlet stage. The fruitlets were also checked for any potential defects caused by the mechanical thinning. At commercial harvest the total yield efficiency per plot was recorded (expressed as average yield efficiency per single tree cross sectional area) and 30 fruit were sampled at each harvest date and brought to our laboratory. Here the 30 fruit were evaluated for any internal and/or external defects. In addition, the following were determined per fruit: weight, length, diameter, firmness and total soluble solids concentration (TSS). Fruit firmness was determined on the opposite, pared sides of the fruit using a 11.1 mm probe on a GÜSS texture analyser (Guss electronic model GS 20, Strand, South Africa), while TSS was determined using a ATAGO® pocket refractometer (PAL-1, The Front Tower Shiba Koen, 23rd floor 2-6-3 Shiba-Koen, Minato-ku, Tokyo 105-0011. Japan).

Statistical analysis

Data were analysed by ANOVA using the linear models procedure of SAS Enterprise guide 5.1 (SAS Institute Incorporated, 100 SAS Campus Drive Cary, North Carolina 27513-2414, USA), and using the LSD test when the F statistic indicated significance at $P < 0.05$.

Results

Hand thinning requirement

The time required to hand thin 'Laetitia' was not significantly reduced by mechanical thinning (Table 3). The 250 and 280 r.p.m. treatments however significantly (52 and 53%, respectively) decreased the number of fruitlets removed compared to the control while the 220 r.p.m. treatment did not differ significantly from the control (Table 3). There seemed to be a linear decrease in thinned fruitlets with an increase in rotor speed (P=0.0866) (Table 3).

In 'African Rose' the time required to hand thin the five tree plots was generally reduced by mechanical thinning (Table 4). At the first hand thinning date, the 220 and 280 r.p.m. treatments reduced the time required to hand thin significantly compared to the control. This was not the case for the 250 r.p.m. treatment, although a 17% reduction was found. At the second hand thinning date, a linear decrease in required thinning time was found with increasing rotors speed. However, only the two higher rotor speeds significantly decreased the hand thinning time compared to the control. This was also the case for the total time to hand thin. The 220, 250 and 280 r.p.m. treatments reduced the total time required to thin by 8, 27 and 38%, respectively. All three machine treatments significantly reduced the number of fruitlets removed during hand thinning at the first, second and combined hand thinning (Table 4). At the first thinning date, no differences were found between rotor speeds, but at the second date the 250 r.p.m. treatment required more thinning than the 220 and 280 r.p.m. treatments. In 'African Delight' all machine thinned treatments reduced hand thinning time (by 48, 45 and52%, respectively) and number of fruitlets thinned (by 73, 71 and 75%, respectively) compared to the control, but the different rotor speeds did not differ from each other (Table 5).

The effect on yield efficiency

At the first harvest date of 'Laetitia' significantly fewer fruit (only 4.6% of total yield) were harvested from the 220 r.p.m. thinned plots compared to the control and 250 r.p.m. treated trees, while the 220 and 280 r.p.m. treatments did not differ from each other (Table 6). At the second harvest date all machine treated trees yielded fewer fruit than the control, but did not differ from each other. A linear decrease in yield efficiency was found with increasing rotor speed for the third harvest date and total yield. Mechanical thinning did not decrease the total yield efficiency compared to the control. A much larger percentage of the crop of the mechanical thinning treatments was harvested on the third harvest date compared to the control.

The yield efficiency per tree of 'African Rose' at the first harvest date was significantly higher for the 220 and 280 r.p.m. treatments, compared to the non-machine thinned control and the 250 r.p.m. treatment (Table 7). The yield efficiency per tree for the second harvest date did not differ between treatments while on the third and fourth harvest dates the yield efficiency per tree was significantly reduced by all three machine treatments. The three machine treatments did not differ significantly from each other. The total yield efficiency per tree in the case of 'African Rose' was not significantly reduced by machine thinning. Machine thinning seemed to increase and decrease the proportion of the crop removed at the second and fourth picks, respectively. Machine thinning reduced the yield efficiency per tree in 'African Delight' by ca. 53 to 55% (Table 8).

Fruit size

Machine thinning increased the weight and diameter, but not the length of 'Laetitia' fruit at the first harvest (Table 9). The three machine treatments did not differ significantly from each other. This effect was also found for the second harvest date with the fruit weight, length and diameter significantly increased by machine thinning, but fruit length was only significantly increased by the 220 and 250 r.p.m. treatments (Table 10). The fruit length of the 220 and 250 r.p.m. treatments did not differ significantly from the 280 r.p.m. treatment (Table 10). For the third harvest date, there were no significant effects on fruit size (Table 11). When combining data for all three harvest dates, the fruit weight and diameter were significantly and equally increased by all three machine treatments (Table 12). Fruit length was not significantly affected at all (Table 12).

In 'African Rose', the fruit size as indicated by the fruit weight, length and diameter was significantly increased at the first harvest date by all three mechanical thinning treatments relative to the control (Table 13). The fruit weight, diameter and length (P=0.0506) showed a quadratic response to rotor speed with the 250 r.p.m. treatment less effective in increasing fruit dimensions. For the second harvest date, the fruit weight, length and diameter were significantly increased by all three machine treatments compared to the control (Table 14). In the case of the fruit weight and diameter the effect of the 280 r.p.m. treatment was significantly greater than that of the 250 r.p.m. treatment, but did not differ significantly from the 220 r.p.m. treatment. The 220 and 250 r.p.m. treatments also did not differ significantly from each other. Fruit length increased linearly with increasing rotor speed. For the third harvest date, the 280 and 220 r.p.m. treatments significantly increased the fruit weight and length compared to the non-machine thinned control while the control and the 250 r.p.m. treatment did not differ significantly from each other (Table 15). The 220 r.p.m. treatment did not differ from the 250 r.p.m. or the 280 r.p.mm. treatments. The fruit diameter was significantly increased by the 220 r.p.m. treatment, but not by the 250 and 280 r.p.m. treatments. The three machine treatments did not differ from each other. The fruit weight, length and diameter were significantly increased for the fourth harvest date by the 220 and 280 r.p.m. treatments compared to the control and the 250 r.p.m. treatment, which did not differ from each other (Table 16). For the combined fruit size data, the fruit weight, length and diameter were increased by all three machine treatments (Table 17). For all three parameters, a quadratic response with rotor speed was found with the 250 r.p.m. treatment less effective in increasing fruit dimensions than 280 r.p.m. In 'African Delight', the fruit weight, length and diameter were not significantly increased by any of the three machine treatments (Table 18).

Fruit quality

Fruit quality in 'Laetitia' was quantified by measuring the fruit firmness and TSS. There were no significant effects on the fruit quality at any harvest date or in the combined data (Table 9, 10, 11, 12).

In 'African Rose', no significant differences in fruit firmness, TSS or split pit were found at the first, second, third and fourth harvest dates, or on the combined data (Table 13, 14, 15, 16, 17). In the case of 'African Delight', in addition to the above mentioned parameters, we also determined the percentage cracked fruit. Machine thinning had no effect on fruit firmness, TSS or split pit, but the 280 and 310 r.p.m. treatments significantly increased the percentage cracked fruit compared to the control (Table 18). The non-machine control and the 250 r.p.m. treatment did not differ significantly from each other. The percentage cracked fruit increased linearly with increasing rotor speed.

Discussion

Weber and Rheinpfalz (2013) found that mechanical thinning with the BAUM mechanical thinning machine consistently reduced the requirement for hand thinning in European plums. In our trials performed with the Darwin 300™, the same effect was found for the Japanese cultivars Laetitia, African Rose and African Delight although the time required to hand thin was not significantly reduced in the case of 'Laetitia'. In the case of 'African Rose', the effect was smaller with the time required to hand thin only reduced by 8, 27 and 38% for the 220, 250 and 280 r.p.m. treatments, respectively. 'African Rose' has a very high initial fruit set as it is self-compatible (http://www.culdevco.co.za/images/stories/african%20rose%20pr00-01%20%282009%29.pdf), therefore following mechanical thinning during bloom a high percentage of the remaining flowers still set. The effect on the time required for hand thinning was therefore less pronounced and it was therefore decided to perform thinning on the later blooming 'African Delight' with higher rotor speeds. The effect was therefore more pronounced for the 'African Delight', with the time required to hand thin reduced by 48, 35 and 52% for the 250, 280 and 310 r.p.m. treatments, respectively. This enhanced effect could be because of the vigorous shoot growth in the lower parts of the canopy of the 'African Rose' trees (Personal observation). These shoots growing into the tractor row decreased the thinning efficiency by impeding the rotor and keeping the spindle away from the trunk. These strong growing laterals were not found in the 'African Delight' and therefore the thinning efficiency was probably higher. Schupp et al. (2008) found that branches longer than 70 cm had a negative effect on the thinning success. Baugher et al. (2009) added that overlapping branches prevent the spindle from reaching all the shoots resulting in under thinning. Machine thinning had a more pronounced effect on the number of fruitlets removed during hand thinning compared to the time required for hand thinning, except for the 220 r.p.m. treatment in the case of 'Laetitia'. Here the number of fruitlets thinned was reduced by 20% compared to the 35% reduction in the time required to hand thin. For the 250 and 280 r.p.m. treatments the number of fruitlets removed was reduced by 52 and 53%, respectively. As was the case for the time required to hand thin, the percentage reduction in the number of fruitlets that had to be thinned was lower (41, 37 and 43% for the 220, 250 and 280 r.p.m. treatments, respectively) in the case of the 'African Rose' . In the case of 'African Delight', the effect was increased through the increase in rotor speed. The fact that the effect is more pronounced on the number of fruitlets removed, compared to the time required to hand thin could be because of the time it takes to move, place and utilise the ladders as discussed in Paper 1.

The total yield efficiency of 'Laetitia' was not significantly reduced although a reduction of 20 and 22% were found for the 250 and 280 r.p.m. treatments, respectively. This was also found in 'African Rose' where the yield efficiency per tree was reduced by ca. 21% for all three machine treatments, but this reduction was also not significant. However, when the rotor speed was increased in the 'African Delight', machine thinning reduced the yield efficiency per tree by ca. 54%. Baugher et al. (2010) found that a reduction in the time required for follow-up hand thinning in peaches and nectarines was correlated to a reduction in crop load. The bigger reduction in yield efficiency per tree in 'African Delight' could be due to the increased rotor speed or the fact that the trees had a very low set. In contrast to our results, Reighard and Byers (2009) suggested that mechanical bloom thinning in peaches can result in a 10 to 30% increase in fruit size and yield when compared to hand thinning 40 to 50 days after full bloom.

In the case of 'African Rose' the percentage of the total yield harvested over the first two harvests was higher for the machine treatments compared to the control. For the non-machine thinned control more than 60% of the total harvest was picked during the last two harvests. This could indicate an advancement of the fruit maturity by the thinning treatments. Earlier maturation was also found by Myers et al. (1993) in 'Winblo' peach and 'Fantasia' nectarine. This was not found for the 'Laetitia', where the inverse was found. 61% of the total harvest in the case of the control was harvested during the first two harvests and only 39% at the third harvest. For the 220, 250 and 280 r.p.m. treatments, 62, 46 and 52% of the total harvest was picked at the third harvest, respectively. Therefore, earlier maturation of fruit is cultivar dependent.

Webster and Spencer (2000), found that an increase in fruit size could be achieved in European plum 'Victoria' when the number of leaves per fruit was increased to four. A further increase in leaf to fruit ratio would not result in bigger fruit (Webster and Spencer 2000). Under Norwegian conditions, Seehuber et al. (2011) found that this value should be a 6-10:1 relationship, for the relatively large fruiting cultivar Victoria. Seehuber et al. (2011) reported that the fruit weight of 'Ortenauer' European plum was increased by 4g whereas the time required for hand thinning was reduced by 33% with a 300 r.p.m. treatment with the BAUM. The same results were found when the rotor speed was increased to 400 or 500 r.p.m. (Seehuber et al. 2011). In 'Laetitia' the time required to hand thin was reduced by 35, 42 and 45% for the 220, 250 and 280 r.p.m. treatments, respectively. We found that a linear increase in the rotor speed did not result in a linear increase in the fruit size. The fruit weight and diameter were consistently increased by all three treatments, but the three machine treatments did not differ significantly from each other. The fruit length was increased, but did not differ significantly from the non-machine control. The same effect was found in the case of 'African Rose', but there the fruit length was also significantly increased. With the time required for hand thinning being linearly reduced by 8, 27 and 38% by the 220, 250 and 280 r.p.m. treatments, it would have been expected that there should be a linear increase in the fruit size. This was not found with the fruit weight being increased by 7, 5 and 9g for the 220, 250 and 280 r.p.m. treatments, respectively. When the rotor speed was increased in the case of 'African Delight', the time required for hand thinning was reduced by ±50%, but there was not a significant increase in the fruit weight, length or diameter. This could be because of the fact that the fruit that were left on the tree were in clusters, and therefore the increase in fruit size was not significant because of competition in the fruit cluster. The fruit set of the 'African Delight' was also not satisfactory; therefore the optimum number of leaves per fruit was probably already achieved before bloom thinning.

Seehuber et al. (2011) indicated that more than 40% of the fruit on European plum trees needed to be removed before a marked change in the sugar concentration or fruit firmness could be achieved, suggesting similar results were also found in Asian plums. Therefore they found that there was a slight, non-significant increase in the sugar concentration. This was also the case in 'Laetitia', 'African Rose' and 'African Delight' where the fruit firmness, as well as the TSS where not significantly influenced by the reductions in the yield efficiency per tree. In the case of 'African Delight' the yield efficiency per tree was significantly reduced by ±53%, but there was still no significant effect on the fruit firmness or TSS.

With the 50% reduction in the yield efficiency per tree in the case of the 'African Delight', there was a linear increase in the percentage fruit cracking with increasing rotor speed. Therefore, as the number of flowers removed by mechanical bloom thinning increased, the remaining fruit probably grew faster even though fruit size was not significantly increased, although this was not seen in average fruit size of the non-cracked fruit. The mechanical bloom thinning, at higher rotor speeds, and the low fruit set on the trees probably resulted in the fruit cracking, because of an increase in the fruit growth during stage III of fruit growth. Kasai et al. (2008) found that an increase in fruit growth rate in 'Fuji' apples resulted in the increase of internal ring cracking. The first symptoms of internal ring cracking were found 92 days after full bloom, with a rapid increase in the symptoms 120 days after full bloom.

In conclusion, mechanical thinning of Japanese plums with the Darwin 300™ has potential to reduce the time reuired to hand thin, but it should be remembered that over thinning with too high spindle speeds could lead to a reduction in yield efficiency, increase fruit size too much and lead to fruit cracking in susceptible cultivars. The optimal rate of thinning needs to be determined for each cultivar individually.

References

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

Baugher TA, Schupp JR, Lesser KM, Hess-Reichard K. 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 TA, Schupp J, Miller S, Harsh M, Lesser K, Reichard K, Sollenberger E, Armand M, Kammerer L, Reid M, Rice L, Waybright S, Wenk B, Tindall M, Moore E. 2008. Chemical and mechanical thinning of peaches. *Pennsylvania Fruit News* 88: 16-17.

Byers RE. 1989. Response of peach trees to bloom thinning. *Acta Horticulturae* 254: 125-132.

Costa G, Vizzotto G. 2000. Fruit thinning of peach trees. *Plant Growth Regulation* 31: 113-119.

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

González-Rossia D, Reig C, Juan M, Agustí M. 2007. Horticultural factors regulating effectiveness of GA_3 inhibiting flowering in peaches and nectarines (*Prunus persica L.* Batsch). *Scientia Horticulturae* 111: 352-357.

Hehnen D, Hanrahan I, Lewis K, Mcferson J, Blanke M. 2012. Mechanical flower thinning improves fruit quality of apples and promotes consistent bearing. *Scientia Horticulturae* 134: 241–244.

Kasai S, Hayama H, Kashimura Y, Kudo S, Osanai Y. 2008. Relationship between fruit cracking and expression of the gene *MdEXPA3* in 'Fuji' apples (*Malus domestica Borkh.*). *Scientia Horticulturae* 116: 194-198.

Myers SC, King A, Savelle AT. 1993. Bloom thinning of 'Winblo' peach and 'Fantasia' nectarine with monocarbamide dihydrogensulfate. *HortScience* 28(6): 616-617.

Miller SS, Schupp JR, Baugher TA, Wolford SD. 2011. Performance of mechanical thinners for bloom or green fruit thinning in peaches. *HortScience* 46(1): 43-51.

Reighard GL, Byers RE. 2009. Peach thinning. Available:

www.ent.uga.edu/peach/peachhbk/cultural/thinning.pdf.

Rosa UA, Cheetancheri KG, Gliever CJ, Lee SH, Thompson J, Slaughter DC. 2008. An electro-mechanical limb shaker for fruit thinning. *Computers and electronics in agriculture* 61: 213-221.

Schupp JR, Baugher TA, Miller SS, Harsh RM, Lesser KM, 2008. Mechanical thinning of peach and apple trees reduces labor input and increases fruit size. *HortTechnology* 18(4): 660-670.

Seehuber C, Damegrow L, Blanke M, 2011. Regulation of source: sink relationship, fruit set, fruit growth and fruit quality in European plum (*Prunus domestica* L.)-using thinning for crop load management. *Plant Growth Regulation* 65: 335-341.

Solomakhin AA, Blanke MM, 2010. Mechanical flower thinning improves the fruit quality of apples. *Journal of Science of Food and Agriculture* 90: 735-741.

Weber HJ, Rheinpfalz DLR, 2013. Chemical and mechanical thinning of plums. *Acta Horticulturae* 998: 51-60.

Webster AD, Spencer JE, 2000. Fruit thinning plums and apricots. *Plant Growth Regulation* 31: 101-112.

Table 1: A summary of the orchard history the cultivars Laetitia, African Rose and African Delight.

Cultivar	Previous yield (ton.ha^{-1})
‘Laetitia’	22
‘African Rose’	17
‘African Delight’	3

Table 2: A summary of the dates of full bloom thinning, fruitlet thinning and harvest, for the cultivars Laetitia, African Rose and African Delight.

Phenological stage	2011/2012 season	2012/2013 season
	'Laetitia'	
Full bloom mechanical thinning	8 September 2011	
Fruitlet hand thinning	11 November 2011	
Harvest	1,6,9 February 2012	
	'African Rose'	
Full bloom mechanical thinning		8 August 2012
Fruitlet hand thinning		20 September 2012
		5 October 2012
Harvest		15, 19, 20, 22 November 2012
	'African Delight'	
Full bloom mechanical thinning		3 September 2012
Fruitlet hand thinning		9 November 2012
Harvest		26 February 2013

Table 3: The efficacy of mechanical thinning at full bloom with the Darwin 300™ on the requirement for hand thinning and the number of fruitlets removed per three-tree plot in 'Laetitia' (2011/2012).

Treatment	Fruitlet stage	
	Hand thinning time (min)	Number of fruitlets removed
Control (only handthinned)	13.6 NS	1079 A
220 r.p.m.	8.8	866 Ab
250 r.p.m.	7.8	514 B
280 r.p.m.	7.4	502 B
Significance level	*0.1107*	*0.0446*
Significance level (Linear)	*0.5780*	*0.0866*
Significance level (Quadratic)	*0.9009*	*0.3119*

NS Non-significant

Table 4: The efficacy of mechanical thinning at full bloom with the Darwin 300™, on the requirement for hand thinning and number of fruitlets removed per five-tree plot in 'African Rose' (2012/2013).

Treatment	Fruitlet stage											
	Hand thinning time (min)[1]		Hand thinning time (min)[2]		Total hand thinning time (min)		Number of fruitlets removed [1]		Number of fruitlets removed [2]		Number of fruitlets removed	
Control (only handthinned)	11.5	a	9.3	a	20.8	a	7836	A	2201	a	10037	a
220 r.p.m.	9.3	b	9.8	a	19.1	a	4863	B	1044	c	5907	b
250 r.p.m.	9.5	ab	5.6	b	15.1	b	4892	B	1401	b	6293	b
280 r.p.m.	8.2	b	4.7	b	12.9	b	4771	B	96	c	5737	b
Significance level	*0.0255*		*0.0001*		*0.0005*		*<0.0001*		*<0.0001*		*<0.0001*	
Significance level (Linear)	*0.2906*		*0.0001*		*0.0019*		*0.8669*		*0.5905*		*0.7686*	
Significance level (Quadratic)	*0.4035*		*0.1111*		*0.5681*		*0.8739*		*0.0037*		*0.3507*	

[NS] Non-significant

[1] First hand thinning date

[2] Second hand thinning date

Table 5: The efficacy of mechanical thinning at full bloom with the Darwin 300^{TM}, on the requirement for hand thinning and number of fruitlets removed per five-tree plot in 'African Delight' (2012/2013).

Treatment	Fruitlet stage	
	Hand thinning time (min)	Number of fruitlets removed
Control (only handthinned)	2.9 a	255 A
250 r.p.m.	1.5 b	68 B
280 r.p.m.	1.9 b	74 B
310 r.p.m.	1.4 b	65 B
Significance level	*0.0081*	*0.0055*
Significance level (Linear)	*0.7714*	*0.9629*
Significance level (Quadratic)	*0.2476*	*0.8832*

^{NS} Non-significant

Table 6: The effect of thinning at full bloom with the Darwin 300™ on the yield efficiency per tree (kg.cm^{-2}) of 'Laetitia' (2011/2012).

Treatment	Yield efficiency per tree (kg cm^{-2}) at first harvest and percentage of harvest			Yield efficiency per tree (kg cm^{-2}) at second harvest and percentage of harvest			Yield efficiency per tree (kg cm^{-2}) at third harvest and percentage of harvest			Total yield efficiency per tree (kg cm^{-2})		Yield (ton ha^{-1})
	kg cm^{-2}		%	kg cm^{-2}		%	kg cm^{-2}		%			
Control (only handthinned)	0.039	a	(9.8)	0.205	a	(51.1)	0.154	NS	(39.1)	0.398	NS	44.8
220 r.p.m.	0.021	b	(4.6)	0.156	b	(33.5)	0.284		(61.8)	0.461		51.6
250 r.p.m.	0.034	a	(11.5)	0.130	b	(42.7)	0.154		(45.8)	0.318		39.6
280 r.p.m.	0.030	ab	(9.5)	0.118	b	(38.2)	0.163		(52.3)	0.311		38.6
Significance level	*0.0317*			*0.0185*			*0.0738*			*0.1304*		.
Significance level (Linear)	*0.0874*			*0.1056*			*0.0375*			*0.0467*		.
Significance level (Quadratic)	*0.0639*			*0.7031*			*0.1305*			*0.2436*		.

NS Non-significant

Table 7: The effect of thinning at full bloom with the Darwin 300™ on the yield efficiecy per tree (kg cm^{-2}) of 'African Rose' (2012/2013).

Treatment	Yield efficiency per tree (kg cm^{-2}) at first harvest and percentage of harvest			Yield efficiency per tree (kg cm^{-2}) at second harvest and percentage of harvest			Yield efficiency per tree (kg cm^{-2}) at third harvest and percentage of harvest			Yield efficiency per tree (kg cm^{-2}) at fourth harvest and percentage of harvest			Total yield efficiency per tree (kg cm^{-2})		Yield (ton ha^{-1})
	kg cm^{-2}		%	kg cm^{-2}		%	kg cm^{-2}		%	kg cm^{-2}		%			
Control (only handthinned)	0.007	b	(3.3)	0.067	NS	(31.4)	0.071	a	(32.2)	0.074	a	(33.1)	0.219	NS	30
220 r.p.m.	0.011	a	(6.2)	0.076		(44.8)	0.050	b	(26.9)	0.040	b	(22.1)	0.176		25
250 r.p.m.	0.008	b	(4.7)	0.072		(41.6)	0.048	b	(28.2)	0.046	b	(25.5)	0.175		26
280 r.p.m.	0.012	a	(6.9)	0.073		(44.2)	0.047	b	(27.4)	0.036	b	(21.5)	0.168		25
Significance level	*0.0067*			*0.7013*			*0.0398*			*0.0001*			*0.0888*		.
Significance level (Linear)	*0.6069*			*0.7486*			*0.7279*			*0.6618*			*0.6980*		.
Significance level (Quadratic)	*0.0103*			*0.7144*			*0.9905*			*0.2085*			*0.8851*		.

NS Non-significant

Table 8: The effect of thinning at full bloom with the Darwin 300™, on the yield efficiency per tree (kg cm^{-2}) in 'African Delight' (2012/2013).

Treatment	Total yield efficiency per tree (kg cm^{-2})		Yield (ton/ha^{-1})
Control (only handthinned)	0.704	a	13
250 r.p.m.	0.314	b	6
280 r.p.m.	0.324	b	7
310 r.p.m.	0.322	b	6
Significance level	*0.0007*		.
Significance level (Linear)	*0.9338*		.
Significance level (Quadratic)	*0.9375*		.

NS Non-significant

Table 9: Effect of mechanical thinning with Darwin 300™ at full bloom compared only hand thinning on fruit quality at the first harvest of 'Laetitia' (2011/2012).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*
Control (only handthinned)	85.4 b	52.5 b	56.6 [NS]	9.1 [NS]	10.90 [NS]
220 r.p.m.	96.5 a	54.9 a	59.0	9.3	11.00
250 r.p.m.	98.4 a	55.3 a	59.0	9.3	11.27
280 r.p.m.	102.6 a	56.1 a	58.9	9.1	11.07
Significance level	0.0401	0.0417	0.1166	0.4664	0.8676
Significance level (Linear)	0.2239	0.2371	0.9065	0.2502	0.8871
Significance level (Quadratic)	0.7938	0.7907	0.8791	0.7069	0.5712

[NS] Non-significant; * Total soluble solids concentration

Table 10: Effect of mechanical thinning with Darwin 300™ at full bloom compared only hand thinning on fruit quality at the second harvest of 'Laetitia' (2011/2012).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*
Control (only handthinned)	87.2 b	52.8 b	55.9 b	9.1 NS	10.10 NS
220 r.p.m.	97.5 a	55.0 a	57.4 a	8.6	10.47
250 r.p.m.	99.0 a	55.1 a	57.4 a	8.3	11.00
280 r.p.m.	97.6 a	55.0 a	56.7 ab	8.0	11.00
Significance level	*0.0034*	*0.0008*	*0.0266*	*0.7055*	*0.3162*
Significance level (Linear)	*0.9532*	*0.9458*	*0.1228*	*0.5676*	*0.3401*
Significance level (Quadratic)	*0.4305*	*0.7990*	*0.3340*	*0.9742*	*0.5716*

NS Non-significant; * Total soluble solids concentration

Table 11: Effect of mechanical thinning with Darwin 300^{TM} at full bloom compared only hand thinning on fruit quality at the third harvest of 'Laetitia' (2011/2012).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*
Control (only handthinned)	90.7 ^{NS}	53.9 ^{NS}	55.9 ^{NS}	8.2 ^{NS}	10.20 ^{NS}
220 r.p.m.	94.3	54.5	56.3	8.6	10.00
250 r.p.m.	96.8	55.0	57.0	8.4	10.53
280 r.p.m.	96.6	55.1	56.8	8.4	10.63
Significance level	*0.6184*	*0.6151*	*0.8866*	*0.3211*	*0.3691*
Significance level (Linear)	*0.6632*	*0.5297*	*0.7758*	*0.2704*	*0.1377*
Significance level (Quadratic)	*0.7538*	*0.8039*	*0.7135*	*0.7656*	*0.5241*

^{NS} Non-significant; * Total soluble solids concentration

Table 12: Effect of mechanical thinning with Darwin 300^{TM} at full bloom compared only hand thinning on fruit quality at the total yield of 'Laetitia' (2011/2012).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*
Control (only handthinned)	88.2 b	53.2 b	55.9 ^{NS}	8.8 ^{NS}	10.20 ^{NS}
220 r.p.m.	95.4 a	54.7 a	56.8	8.6	10.20
250 r.p.m.	98.3 a	55.2 a	57.5	8.4	10.84
280 r.p.m.	97.9 a	55.2 a	57.0	8.3	10.81
Significance level	*0.0159*	*0.0161*	*0.3576*	*0.8247*	*0.2823*
Significance level (Linear)	*0.3321*	*0.2811*	*0.7922*	*0.5461*	*0.1767*
Significance level (Quadratic)	*0.4404*	*0.6550*	*0.4611*	*0.9498*	*0.3748*

^{NS} Non-significant; * Total soluble solids concentration

Table 13: Effect of mechanical thinning with Darwin 300™ at full bloom compared only hand thinning on fruit quality at the first harvest of 'African Rose' (2012/2013).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*	Percentage Split pit
Control (only handthinned)	54.5 c	45.2 c	42.3 b	5.0 NS	11.39 NS	0.0 NS
220 r.p.m.	64.5 a	47.9 a	45.2 a	5.2	11.12	1.3
250 r.p.m.	60.4 b	46.8 b	44.3 a	5.2	11.22	0.7
280 r.p.m.	62.6 ab	47.4 ab	45.1 a	5.3	11.42	1.3
Significance level	*<.0001*	*<.0001*	*<.0001*	*0.3828*	*0.2471*	*0.4880*
Significance level (Linear)	*0.2197*	*0.2679*	*0.8564*	*0.6515*	*0.0825*	*1.0000*
Significance level (Quadratic)	*0.0197*	*0.0185*	*0.0506*	*0.8261*	*0.7312*	*0.4434*

NS Non-significant; * Total soluble solids concentration

Table 14: Effect of mechanical thinning with Darwin 300™ at full bloom compared only hand thinning on fruit quality at the second harvest of 'African Rose' (2012/2013).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*	Percentage split pit
Control (only handthinned)	59.4 c	46.9 c	43.3 c	4.5 NS	11.59 NS	0
220 r.p.m.	66.3 ab	48.7 ab	45.1 b	4.6	11.19	0
250 r.p.m.	65.9 b	48.5 b	45.2 ab	4.4	11.68	0
280 r.p.m.	69.5 a	49.5 a	46.1 a	4.6	10.44	0
Significance level	*<.0001*	*<.0001*	*<.0001*	*0.5733*	*0.4464*	
Significance level (Linear)	*0.0739*	*0.1035*	*0.0324*	*0.8716*	*0.3770*	
Significance level (Quadratic)	*0.2053*	*0.1503*	*0.3341*	*0.1821*	*0.2420*	

NS Non-significant; * Total soluble solids concentration

Table 15: Effect of mechanical thinning with Darwin 300[TM] at full bloom compared only hand thinning on fruit quality at the third harvest of 'African Rose' (2012/2013).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*	Percentage split pit
Control (only handthinned)	57.7 c	46.4 b	43.2 c	4.6 [NS]	11.52 [NS]	0
220 r.p.m.	63.4 ab	48.1 a	44.4 ab	4.8	11.48	0
250 r.p.m.	61.0 bc	47.4 ab	43.6 bc	4.8	11.73	0
280 r.p.m.	65.5 a	48.5 a	44.7 a	4.7	11.43	0
Significance level	*0.0086*	*0.0063*	*0.0234*	*0.5713*	*0.9335*	
Significance level (Linear)	*0.3465*	*0.4337*	*0.5200*	*0.6205*	*0.9201*	
Significance level (Quadratic)	*0.0749*	*0.0841*	*0.0385*	*0.9454*	*0.5257*	

[NS] Non-significant; * Total soluble solids concentration

Table 16: Effect of mechanical thinning with Darwin 300[TM] at full bloom compared only hand thinning on fruit quality at the fourth harvest of 'African Rose' (2012/2013).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*	Percentage split pit
Control (only handthinned)	54.1 b	45.4 b	42.5 b	5.1 [NS]	11.45 [NS]	0
220 r.p.m.	61.0 a	47.3 a	44.2 a	5.2	11.44	0
250 r.p.m.	56.5 b	46.1 b	43.2 b	5.3	11.38	0
280 r.p.m.	61.4 a	48.1 a	44.8 a	5.1	11.75	0
Significance level	*<.0001*	*<.0001*	*<.0001*	*0.7561*	*0.4775*	
Significance level (Linear)	*0.0576*	*0.0883*	*0.2282*	*0.6691*	*0.2339*	
Significance level (Quadratic)	*0.0003*	*0.0006*	*0.0015*	*0.3529*	*0.3382*	

[NS] Non-significant; * Total soluble solids concentration

Table 17: Effect of mechanical thinning with Darwin 300™ at full bloom compared only hand thinning on fruit quality at total yield of 'African Rose' (2012/2013).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*	Percentage split pit
Control (only handthinned)	57.0 c	46.2 c	43.0 c	4.8 NS	11.50 NS	0.0 NS
220 r.p.m.	64.3 ab	48.2 ab	44.7 ab	4.8	11.31	0.0
250 r.p.m.	62.1 b	47.6 b	44.2 b	4.8	11.60	0.0
280 r.p.m.	67.0 a	48.8 a	45.4 a	4.8	11.00	0.0
Significance level	*<.0001*	*<.0001*	*<.0001*	*0.9148*	*0.5556*	*0.3664*
Significance level (Linear)	*0.0775*	*0.1317*	*0.0740*	*0.9788*	*0.4924*	*0.7361*
Significance level (Quadratic)	*0.0060*	*0.0064*	*0.0114*	*0.6067*	*0.2560*	*0.2563*

NS Non-significant; * Total soluble solids concentration

Table 18: Effect of mechanical thinning with Darwin 300™ at full bloom compared only hand thinning on fruit quality at the total yield of 'African Delight' (2012/2013).

Treatment	Fruit weight (g)	Fruit diameter (mm)	Fruit length (mm)	Fruit firmness (kg)	TSS (%)*	Percentage cracked fruit	Percentage split pit
Control (only handthinned)	144.0 NS	65.2 NS	58.3 NS	7.9 NS	15.25 NS	7.5 c	6 NS
250 r.p.m.	140.6	64.7	56.9	8.2	16.08	13.0 bc	3
280 r.p.m.	142.7	65.3	57.3	8.6	15.66	19.5 ab	10
310 r.p.m.	147.6	66.0	63.5	7.8	15.81	21.0 a	7
Significance level	*0.4858*	*0.3008*	*0.2832*	*0.0828*	*0.3181*	*0.0011*	*0.4314*
Significance level (Linear)	*0.1363*	*0.0650*	*0.0881*	*0.2526*	*0.5546*	*0.0194*	*0.3902*
Significance level (Quadratic)	*0.7338*	*0.9277*	*0.3868*	*0.0375*	*0.4657*	*0.3711*	*0.1693*

NS Non-significant; * Total soluble solids concentration

PAPER 3: THE EFFIENCY OF CHEMICAL THINNING ON THE REDUCTION OF HAND THINNING TIME, WHILE MAINTAINING THE FRUIT QUALITY IN JAPANESE PLUMS

Abstract

The thinning of stone fruit is important in order to produce fruit of high quality, with the appropriate fruit size. Hand thinning contributes largely to the total production cost, as it is labour intensive and labour costs are increasing. The efficacy of gibberellic acid and gibberellin spray treatments at pit hardening in reducing the time required for hand thinning in 'Laetitia', 'Larry Ann', 'African Rose' and 'Pioneer' Japanese plum orchards was evaluated in consecutive seasons while also determining the yield, fruit size and quality and the return bloom. The trials on 'Laetitia' and 'Larry Ann' were performed at the Welgevallen research farm, in the Stellenbosch area, South Africa over the 2011/2012 and 2012/2013 seasons. Trees on the rootstock 'SAPO 778' were planted at a spacing of 4.5 x 1.5 m in 1992 and 1998, respectively. The trees are trained to a 7-wire hedge system ('Laetitia') and a slender spindle ('Larry Ann'). During 2012/2013, trials were also performed on 'Pioneer', on the farm Klein-Simonsvlei and 'African Rose' on the farm Babylonstoren, Simondium, South Africa. The 'Pioneer' and 'African Rose' trees on the rootstock 'Marianna' were planted at a spacing of 4.5 x 1.5 m in 2001 and 2009, respectively, and are trained to a 7-wire hedge system. The trees where sprayed until run-off with motorised knapsack sprayers. A non-sprayed control was used for all the cultivars. A foliar application of 100 mg L^{-1} GA_3 (ProGibb®, Philagro SA, Somerset West, South Africa) and 100 mg L^{-1} GA_{4+7} (Regulex®, Philagro SA, Somerset West, South Africa) was applied at pit hardening in 'Laetitia' and 'Larry Ann'. Foliar applications at pit-hardening for the 'African Rose' and 'Pioneer' were done at 100, 200 and 400 mg L^{-1} for both GA_3 and GA_{4+7}. A randomized complete block design was used, with ten single tree replicates. There was no effect on yield efficiency for the 'Laetitia', 'Larry Ann' and 'Pioneer' in the season of application, but the 'African Rose' fruit maturity was delayed by the GA_3 and GA_{4+7} treatments and the yield efficiency was lower at high GA concentrations. No effect was found on the fruit size, but the GA-treatments influenced the fruit quality by increasing fruit firmness in 'Larry Ann', 'Pioneer' and 'African Rose'. For all three cultivars the GA_{4+7} increased the fruit firmness more than the GA_3-treatment. TSS and the post-storage fruit quality was not affected by the GA-applications for the 'Laetitia', 'Larry Ann', 'Pioneer' or 'African Rose'. The return bloom was significantly influenced in the 'Laetitia' and 'Larry Ann'. For the 'Laetitia', the

GA_3 increased the number of vegetative buds on spurs while on short shoots of trees sprayed with GA_{4+7} the number of reproductive buds containing one flower was decreased. The flower density was hereby decreased and this effect was also observed in 'Pioneer' and 'African Rose', were the GA_3 decreased the flower density more than the GA_{4+7}. In 'Pioneer', both the increase in vegetative buds and decrease in single-flower buds and reduced flower density points towards a reduction in return bloom, which was the aim of the GA applications. No reduction was found in the time required to thin the trees for 'Laetitia', but for 'Larry Ann' both the GA-applications significantly reduced the time required to thin the trees. In the season after application, there was no significant reduction in the yield efficiency and also no increase in the fruit size. Again an increase in the fruit firmness was found, with the GA_{4+7} again increasing the fruit firmness more than the GA_3. When the GA-sprays were applied in consecutive seasons, no effect was found on the time required to thin the trees. The effect of GA-applications on the fruit size and quality, the return bloom and yield, and the fruit size and quality for the following season, was inconsistent. The reduction in return bloom along with the reduction in time required to hand thin illustrated that the two products could be of value to reduce the number of flowers per tree before bloom, especially when applying GA_3 at 100 mg L^{-1} or higher concentrations. The increase in fruit firmness will have a positive effect on the post-storage and -shelf life results, but the fact that the results were inconsistent will restrain the usage of the two products.

Keywords: *Prunus salacina* Lindl., fruit size, return bloom

Introduction

Interest in chemical bloom thinning has increased over the last few years because of the premium paid to producers for larger fruit sizes and the inability of hand thinning to be cost effective (Baugher et al. 2008). Chemical thinners evaluated include caustic materials, growth regulators and photosynthetic inhibitors. In apple production effective chemical thinners are available, but the search continues for an effective stone fruit chemical thinner. Chemical thinners in stone fruit tend to differ with fruit type, orchard and also season (Schupp et al. 2008). Primary advantages of these chemical thinners are that they are quick and easy to use and generally inexpensive (González-Rossia et al. 2007). Even if chemical thinners were found that could be alternatives to hand thinning as main thinning method, hand thinning would still be used after final fruit drop to remove under-sized and damaged fruitlets (Damegrow and Blanke 2009).

Gibberellin (GA) is applied to trees to reduce flower induction, improve fruit quality, possibly delay harvest and improve the storability of the fruit. GA applied during stage III of fruit growth has resulted in firmer and heavier fruit. It also delayed maturity and fruit softening, which could be of great value for late ripening cultivars, but not for the early maturing cultivars (Lurie 2010). Application of GA at the right time and amount influences the differentiation of flower buds (Southwick and Glozer 2000). The fruit set (percentage of flowers that produce fruit) is unaffected by GA application, which enhances the reliability of GA as a chemical thinner (González-Rossia et al. 2006). In citrus, apple and stone fruit the application of GA during the bud induction period reduces the number of flowers (return bloom) for the next spring (González-Rossia et al. 2007). Therefore, in frost free areas it could serve as a reliable method of chemical thinning, reducing the flower numbers per trees, and thus also the hand thinning requirement. The reduction in the number of flower buds, using GAs, is only effective during the induction period (85-100 days after anthesis) of the buds and not the differentiation period (Southwick et al. 1995). The mechanism through which GA_3 inhibits floral bud induction is not known, but in apples it is believed that the source strength of vegetative growth is increased, thereby increasing the usage of carbohydrates (Lenahan et al. 2006). Coetzee and Theron (1999) found that GA_{4+7} applied at 90, 120, 150 and 180 mg L^{-1} four weeks before harvest on 'Sunlite' nectarine, reduced the number of reproductive buds significantly, which resulted in an reduction in the time required to hand thin. Lenahan et al. (2006) found a 65% reduction in the flower density when applying 200 mg L^{-1} GA_3 or GA_{4+7} on 'Bing' cherry. González-Rossia et al. (2006) applied 50 mg L^{-1} GA_3 on the Japanese plums 'Black Gold' and 'Black Diamond', reducing the number of flowers by 31-43% and resulting in a 45 to 47% decrease in the time required for hand thinning.

Lenahan et al. (2006) found that the fruit maturity of cherries was delayed by applications of GA_3 at 50 and 100 mg L^{-1}. They also reported an increase in TSS of 7 or 12%, fruit firmness by 15 or 20% and fruit weight by 7 or 14% (Lenahan et al. 2006). González-Rossia et al. (2007) reported the same effects for peaches and nectarines. The internal fruit quality was also improved, with internal breakdown and bleeding reduced for 'Queen Giant' peach (Lurie 2010). Coetzee and Theron (1999) reported an increase in fruit firmness, but a decrease in TSS, which indicated a delay in fruit ripening in GA_3-treated 'Sunlite' nectarine. This delay in fruit ripening would probably lead to better storage potential (Coetzee and Theron 1999). A decrease in the yield per tree was found the following season (Coetzee and Theron 1999, González-Rossia et al. 2007). This is due to the reduction in the number of reproductive buds, but also because the commercial thinning method was not changed to account for the reduction in reproductive buds on the basal section of the shoots (Coetzee and Theron 1999, González-Rossia et al. 2007). Coetzee and Theron (1999) also reported no increase in mean fruit weight compared to the control, but the fruit distribution was however affected with more large fruit produced compared to the control. In Japanese plum, González-Rossia et al. (2006) reported a decrease in the number of fruit harvested with applications of 75 mg L^{-1} or higher concentrations of GA_3, but it was compensated for by an increase in fruit weight. No detrimental effects were found on the fruit, with the fruit firmness increased in the 'Black Gold', along with improved fruit colour (González-Rossia et al. 2006).

In this paper we report on the efficacy of foliar GA application at pit hardening in reducing return bloom and therefore the requirement for hand thinning in Japanese plum orchards, while also evaluating the effect on yield and fruit quality.

Materials and methods

Plant material and site description

During the 2011/2012 and 2012/2013 seasons, consecutive trials were performed on the same trees, on the Welgevallen research farm (33°56'49.46" S, 18°52'17.29" E), in Stellenbosch, South Africa, on the Japanese plums 'Laetitia' and 'Larry Ann'. The trees on the rootstock 'SAPO 778' were planted at a spacing of 4.5 x 1.5 m in 1992 and 1998, respectively. The trees are trained to a 7-wire hedge system ('Laetitia') and a slender spindle ('Larry Ann'). During 2012/2013, trials were also performed on 'Pioneer' on the farm Klein-Simonsvlei (33°48'32.91" S, 18°55'27.82" E) and 'African Rose' on the farm Babylonstoren (33°49'31.02" S, 18°55'59.42" E), Simondium, South Africa. The 'Pioneer' and 'African Rose' trees on the rootstock 'Marianna' were planted at a spacing of 4.5 x 1.5 m in 2001 and 2009, respectively, and are trained to a 7-wire hedge system. The trees where sprayed until run-off with motorised knapsack sprayers. Orchard history is summarized in Table 1.

Experimental design and treatments

The trees where sprayed until run-off with motorised knapsack sprayers and only sprayed on days where there was no wind at application and the conditions at application led to slow drying of the products. The weather after application was above 18°C to allow for efficient results. A non-sprayed control was used for all the cultivars. A foliar application of 100 mg L^{-1} GA_3 (ProGibb®, Philagro SA, Somerset West, South Africa) and 100 mg L^{-1} GA_{4+7} (Regulex®, Philagro SA, Somerset West, South Africa) was applied at pit hardening in 'Laetitia' and 'Larry Ann'. Foliar applications [1] of GA_3 and GA_{4+7} at pit-hardening was done at 100, 200 and 400 mg L^{-1} for the 'African Rose' and 'Pioneer'. Between each row sprayed a guard row was left untreated with a buffer tree between each sprayed tree in the row. A randomized complete block design was used, with ten single tree replicates. Dates for application, harvest and hand thinning are summarised in Table 2.

Data collection

At commercial harvest the total yield per tree was recorded and 60 fruit per tree were sampled at each harvest date and brought to our laboratory. Trunk cross sectional area was determined and yield expressed as yield efficiency (kg cm^{-2}). For the 'African Rose', the first harvest date was unfortunately missed. At harvest 30 fruit were evaluated for any internal and/or external defects. In addition, for each fruit the following were measured: Weight, length, diameter, firmness and total soluble solids concentration (TSS). Fruit firmness was determined on opposite, peeled sides of the fruit using a 11.1 mm probe on a GÜSS texture analyser (Guss electronic model GS 20, Strand, South Africa), while TSS was determined using a ATAGO® pocket refractometer. In the case of 'Laetitia' and 'Larry Ann', the remaining 30 fruit were stored at -0.5 °C for 42 days. For the 'Pioneer' and 'African Rose' the remaining 30 fruit were stored at -0.5 °C for 10 days, then 10 days at 10 °C, followed by 10 days at 5 °C. After-storage, 15 of the 30 fruit was immediately evaluated for any internal and/or external defects. The remaining 15 fruit were kept at 10 °C for 7 days to simulate shelf life, were after the fruit were assessed for any internal and/or external defects. Defects included the following: Split pit, shrivelling due to moisture loss, decay, aerated fruit, internal browning and gel breakdown. Internal browning and gel breakdown develop due to membrane damage during cold storage. Internal browning is symptomized by the browning of the flesh near the peel of the fruit, while gel breakdown is symptomized by a glasslike shine to the flesh (Singh and Singh 2013). Defects were recorded as a percentage of fruit having the defect.

In 2011/2012, the effect of the GA applications on return bloom was determined by tagging three scaffold branches per 'Laetitia' and 'Larry Ann' tree and monitoring all one-year-old shoots and spurs on these branches. Return bloom was determined by counting all vegetative and reproductive buds that burst in spring, as well as counting the number of flowers per reproductive bud. During 2012/2013, bloom was scored (on a scale of 0-5) to determine the effect of the GA applications on the bloom density. A score of 5 was allocated if a tree had a very high bloom and 0 if there were no flowers on the tree. For all trials the efficacy of thinning was determined by measuring the time required to complete hand thinning per tree as well as the number of fruitlets thinned during commercial hand thinning. In the case of 'Pioneer', the fruit set was low in the 2013/2014 season; therefore no hand thinning was required and fruit per tree were counted just prior to harvest.

Statistical analysis

Data were analysed by ANOVA using the linear models procedure of SAS Enterprise guide 5.1 (SAS Institute Inc., Cary, North Carolina, USA), and using the LSD test when the F-statistic indicated significance at $P<0.05$. For the statistical analysis of the scored values, the data were ranked by block and there after a one-way ANOVA was performed on the ranked data.

Results

Effect on yield efficiency in the season of GA application

No significant differences in yield efficiency were found between the control and GA-treated 'Laetitia' and 'Larry Ann' in the 2011/2012 season (Table 3) or in 'Pioneer' in 2012/2013 (Table 4). In the case of the 'African Rose', the yield efficiency per tree was significantly affected by the GA treatments for the first, third and the total harvest (Table 5). Generally, the GA-treated trees yielded fewer fruit during the first pick ($P=0.0032$). The yield harvested at the first harvest date did not differ between different rates of GA_3, while the GA_{4+7} showed a significant increase at the high rate (Table 5). Although there was no significant effect on the yield efficiency per tree at the second harvest, a quadratic interaction was found between the treatments indicating again a difference in rate response between the two GA types (Table 5). GA-applications significantly increased the yield efficiency per tree harvested at the third date compared to the control (Table 5). Yield efficiency per tree decreased linearly with an increase in GA concentration although the interaction term was also nearly significant (P=0.0569) indicating again that trees respond differently to increasing rates of GA_3 and GA_{4+7} (Table 5). With an increase in GA_3 concentration resulting in an decrease in the yield efficiency per tree, but an increase in the GA_{4+7} concentration did not result in an decrease in the yield efficiency per tree. No significant difference was found in total yield efficiency between the control and the GA-treatments, but there was a linear interaction between rate and GA-type as GA_3 resulted in a decrease in yield with increasing rate while the GA_{4+7} resulted in a decrease of total yield efficiency with a decreasing rate (Table 5).

Effect on fruit size in the season of GA application

During 2011/2012, no significant effects were found on fruit size of 'Laetitia' (Table 6) or 'Larry Ann' (Table 7). In 'Pioneer' no significant effects were found in fruit weight and length, but a quadratic interaction occurred between GA-type and rate for fruit diameter despite the absence of significant differences between treatments (Table 8). Here the fruit diameter decreased as the GA_3 rate was increased, but decreased again as the rate was increased above 200 mg L^{-1}. The effect of the GA_3 was less than that of the GA_{4+7}. For the GA_{4+7} treatment the fruit diameter increased as the rate was increased from 100 to 200 mg L^{-1}, but the fruit diameter decreased again as the rate was increased further (Table 8). In 'African Rose', quadratic interactions were found between GA-type and rate for fruit weight, length and diameter again despite the absence of significant differences between treatments (Table 9). When the rate of the GA_3 was increased from 100 to 200 mg L^{-1}, the fruit weight, length and diameter decreased and increased again as the rate was increased further. For the GA_{4+7} treatment the fruit weight, length and diameter increased when the rate was increased from 100 to 200 mg L^{-1} and increased again as the rate was decreased further (Table 9).

Fruit quality at harvest in the season of GA application

During 2011/2012, GA treatment of 'Laetitia' had no significant effect on fruit firmness and TSS (Table 10). In 'Larry Ann' fruit firmness was increased significantly by GA_{4+7}, while the GA_{4+7} and GA_3

applications did not differ significantly from each other (Table 10). The GA_3 treatment also did not differ significantly from the control, although the fruit firmness of the GA_3 spray treatment was 0.6 kg higher than that of the control. No significant effect was observed in TSS (Table 10).

The fruit firmness was increased significantly in 'Pioneer' by the GA treatments (Table 11). The contrast between the two products indicated that the GA_{4+7} treatments generally increased the fruit firmness more than the GA_3 treatments (Table 11). The TSS showed a linear interaction between the GA-types and rate (Table 11). Here the GA_{4+7} applications increased the TSS more at higher rates while the GA_3 applications were more effective at lower rates. No significant effects were found in split pit (Table 11). In the case of 'African Rose', there were no significant effects on percentage split pit or TSS. Fruit firmness was generally increased by all GA applications relative to the control (P=0.0338) (Table 11).

Fruit quality after storage in the season of GA application

After storage, no significant effect was found in the fruit quality of 'Laetitia' (Table 12). In 'Larry Ann' the fruit firmness was significantly higher in the GA_3 and GA_{4+7} treated fruit compared to the control, but the GA treatments did not differ from each other. No differences were found in other quality parameters, viz. decay, shrivel, internal browning, gel breakdown and split pit (Table 13).

In the case of 'Pioneer' a quadratic interaction was found between GA-type and rate with both GA's resulting in higher firmness at the middle rate but the trend was more pronounced in GA_{4+7} (Table 14). The percentage shrivel, internal browning and gel breakdown was very low and no biologically significant differences occurred while no differences occurred in percentage decay and split pit (Table 14). The fruit firmness after storage of 'African Rose' was higher in GA treated fruit than the control. A linear interaction occurred between GA-type and rate with GA_3 treated fruit firmer at higher rates while GA_{4+7} treated fruit were firmer at lower rates (Table 15). Very low levels of shrivel, gel breakdown, split pit and decay occurred and though some statistically significant effects were found these are not biologically significant (Table 15). A linear increase was found from 1 to 9% for the internal browning when the rate of GA_{4+7} was increased although the control had 7% internal browning (Table 15). In the case of GA_3, a quadratic effect was found with an increase in rate increasing the percentage internal browning from 5 to 12%, but the percentage internal browning decrease again to 7%, as the rate was increased further (Table 15).

Fruit quality after-shelf life in the season of GA application

In ‘Laetitia’ after shelf life significant levels of internal browning was found in GA_3 treated fruit, but no other quality defects were significant (Table 16). The internal browning was 4% higher for the GA_3 treated trees compared to the control (Table 16). In the case of ‘Larry Ann’ the fruit firmness was still significantly higher following the GA_3 treatment compared to the control but did not differ significantly from the GA_{4+7} treatment (Table 17).

In the case of ‘Pioneer’, the GA_{4+7} treatments increased the fruit firmness more than the GA_3 treatments (P=0.0170) (Table 18). For both GA_3 and GA_{4+7}, an increase in the concentration from 100 to 200 mg L^{-1} resulted in an increase in the fruit firmness, but the fruit firmness decreased again after the concentration was increased from 200 to 400mg L^{-1} (Table 18). A quadratic interaction was found between GA-type and rate for internal browning, but generally higher rates of GA_3 decreased internal browning (Table 18). On average, the percentage gel breakdown was increased by GA treatments compared to the control (P=0.0298) with a significant trend that the intermediate GA rate resulted in less gel breakdown than lower and higher rates (Table 18). In ‘African Rose’ the average firmness of GA-treated fruit was still higher after shelf life compared to the control (Table 19). A significant quadratic response between GA-type and rate existed in fruit firmness with GA_3 at the middle rate less effective than the higher rate while for GA_{4+7} all the rates were equally effective in maintaining fruit firmness. Percentage gel breakdown was generally increased by the GA treatments, but more so by the GA_3 treatments (Table 19). The percentage internal browning was higher on average for the GA_3 compared to the GA_{4+7} treatments (Table 19). No other quality parameters were significantly affected by the GA treatments except the percentage aerated fruit, which showed a quadratic interaction between GA-type and rate (Table 19). Here the percentage aerated fruit increased as the rate of GA_{4+7} was increased, but decreased as it was increased further.

Return bloom and hand thinning time required the following season

In ‘Laetitia’ the GA_3 treated trees had significantly more vegetative buds on the spurs compared to the control and the GA_{4+7} application while the control and the GA_{4+7} application did not differ significantly (Table 20). In ‘Larry Ann’, the number of vegetative buds per shoot was increased (non-significant) by both GA treatments while the number of reproductive buds containing only one flower was significantly reduced by the GA_{4+7} treatment while the GA_3 and control did not differ from each other (Table 21). The number of reproductive buds on spurs containing three flowers per bud was significantly higher for the GA_3 and GA_{4+7} applications compared to the control, with the two applications not differing significantly from each other (Table 21). No significant effects were found in the number of vegetative buds on short shoots, the number of reproductive buds containing one, two or three flower buds on short shoots, as well as on spurs of 'Laetitia' (Table 20). For the 'Larry Ann', no significant effects were found in the number of vegetative buds and reproductive buds containing one or two flower buds on spurs and also for the number of reproductive buds containing one, two or three flower per flower bud on short shoots (Table 21).

No significant differences were found in 'Laetitia' between the GA-treatments and the control in terms of the time required to hand thin, and the number and total weight of fruitlets removed by hand thinning (Table 22). In 'Larry Ann' the GA_7 applications significantly reduced the hand thinning time and number and weight of fruitlets thinned compared to the control, but did not differ significantly from each other (Table 23).

In the 2012/2013 season, no significant effect was found in bloom density score, time required to hand thin, the number of fruitlets removed and the total weight of fruitlets removed in 'Laetitia' (Table 24). In the case of 'Pioneers', bloom density was generally reduced by GA treatment ($P<.0001$) and the higher the GA rate, the more the density was reduced, but no significant effect was found for the number of fruitlets on the tree (Table 25). The GA_3 and GA_{4+7} differed significantly from each other ($P=0.0049$), with the GA_3 treatment reducing the flower density more than the GA_{4+7}. In the case of the 'African Rose', GA treatment generally reduced bloom density, while this was more so for GA_3 than GA_{4+7} and the higher the GA rate, the more the flower density was reduced (Table 26). Hand thinning time was reduced by the GA treatments ($P=0.0099$), which also resulted in a decrease in the number of fruitlets removed (Table 26). A linear interaction was also found for the time required to thin the tree ($P=0.0174$), this was illustrated by the GA_3 treatments were an increase in the rate resulted in an decrease in the time required for thinning (Table 26). The number of fruitlets thinned by hand for the control was significantly more compared to the two higher rates for the GA_3 and GA_{4+7} treatments ($P=0.0027$). An increased GA rate also resulted in a linear decrease of the number of fruitlets removed (Table 26).

Effect of GA-applications on yield efficiency and fruit quality in the following season

The yield efficiency and fruit size in the season following GA application was not affected significantly in 'Laetitia' or 'Larry Ann' (Table 27 - 29). Fruit firmness in both 'Laetitia' and 'Larry Ann' was significantly improved by the GA_{4+7} treatment but not GA_3 (Table 30). No significant effects were found in TSS or split pit in 'Laetitia' or 'Larry Ann' (Table 30).

After storage 2012/2013, the fruit firmness of the GA_{4+7} treatment was still significantly higher than that of the control and the GA_3 treatment in both 'Laetitia' and 'Larry Ann' (Table 31, 32). No significant other post storage quality differences were found in 'Laetitia' (Table 31) while in 'Larry Ann' gel breakdown was increased by both GA treatments relative to the control, but the two GA treatments did not differ from each other (Table 32). The percentage of split pit was significantly higher following the GA_3 treatment, compared to the control and the GA_{4+7} treatment (Table 32), but the level of split pit was very low.

After-shelf life the fruit firmness from the GA_{4+7} treatment was still significantly higher than GA_3 treated or control in 'Laetitia' and 'Larry Ann', but the latter two did not differ from each other (Table 33, 34). No significant differences were found in either cultivar in shrivel, decay, internal browning, gel breakdown or split pit.

Discussion

Effect on current season yield efficiency, fruit size and quality

GA application had no significant effects on the yield efficiency of 'Laetitia' and 'Larry Ann' during the 2011/2102 season and in 'Pioneer' during the 2012/2013 season. González-Rossia et al. (2006) also found no effect on current season yield in 'Black Diamond' and 'Black Gold' Japanese plums with GA_3 applications at 50, 75, 100, 125 and 150 mg L^{-1}. A significant decrease in total yield efficiency was found following the 400 mg L^{-1} GA_3 treatment in 'African Rose', which resulted in a significant interaction between GA-type and rate. This reduction in the yield in the current season has not been observed in stone fruit before, but implies that very high rates of GA_3 applied at pit hardening could damage reproductive buds. In 'African Rose', the yield efficiency for the first harvest date was lower for the GA treatments, compared to the control. The inverse was found for the third harvest, were the yield efficiency was higher for the GA treatments compared to the control indicating that the GA-applications delayed maturity. Lurie (2010) reported a similar effect on apricots and peaches with GA_3 concentrations from 10 to 120 mg L^{-1}.

Fruit size was not significantly influenced by the GA-applications in 'Laetitia' and 'Larry Ann' and even at higher concentration there was no significant effect on the fruit size in 'Pioneer' and 'African Rose'. This was despite the significant decrease in 'African Rose' yield efficiency and in contrast with Lurie (2010) who found that GA_3 applications at concentrations between 10 to 120 mg L^{-1} increased the fruit weight in cherries.

Fruit firmness of 'Laetitia' was not significantly influenced by the GA_3 and GA_{4+7} 100 mg L^{-1} applications during the 2011/2012 season. In 'Larry Ann', 'Pioneer' and 'African Rose' the application of GA_3 and GA_{4+7} resulted in a higher fruit firmness at harvest, post-storage and after – shelf life. Our results indicated that the GA_{4+7} application had a bigger effect on the fruit firmness compared to the GA_3 treatment, although this effect was not found for all the cultivars at the harvest, post-storage and shelf life stages. Lurie (2010) found an increase in fruit firmness with GA_3 on cherries and peaches. Webster and Spencer (2000) also found this increase in fruit firmness when applying GA_3 to European plums and apricots. Southwick and Fritts (1995) found that 39.9 and 118.6 g ha^{-1} increased the fruit firmness in 'Queen Crest' peach, but the lower concentration increased the fruit firmness the most. This was not found in the case of 'Friar' plum where both the 59.3 and 118 g ha^{-1} treatments increased the fruit firmness, but the higher concentration increased the fruit firmness the most (Southwick and Fritts 1995). Coetzee and Theron (1999) also reported an increase in fruit firmness, but they found no linear or quadratic trends with concentration. Why cultivars differ in their response to GAs is uncertain, but probably can be attributed to stage of fruit development during application. González-Rossia et al. (2007) reported that the application of GA_3 during the induction period would result in an increase in cell enlargement of the fruit. This therefore would result in bigger fruit, which is firmer. The fact that our results did not illustrate an increase in fruit size, could be due to the use of mean fruit size rather than the size distribution. This was found by Coetzee and Theron (1999), where they did not find an increase in fruit size when measuring mean fruit size, but found the effect in the size distribution.

Webster and Spencer (2000) found that a pre-harvest GA_3-application reduced the soluble solids concentration in 'Friar' and 'Black Amber' Japanese plum, but not consistently, while Southwick and Fritts (1995) also applying GA_3, found an increase in TSS in the same cultivars. Coetzee and Theron (1999) indicated that there was no effect on TSS when GA_3 was applied pre-harvest. In our trials the

TSS was not increased by the GA-applications compared to the control, but in 'Pioneer' all the GA_{4+7} treatments increased the TSS significantly compared to the GA_3 400 mg L^{-1} treatment. TSS did not differ significantly in 'Laetitia' and 'Larry Ann' during the 2011/2012 season and in 'African Rose' during the 2012/2013 season.

Coetzee and Theron (1999) and Lurie (2010) argued that the application of GA_3 and GA_{4+7} resulted in delayed ripening of fruit and thereby would result in a better storage potential by delaying storage disorders such as internal browning and woolliness. In 'African Rose' shrivelling was reduced during storage by GA application, but this effect was not seen after shelf life. The reduced shrivelling could be because of the increased fruit firmness associated with the application of GA, but it is interesting that the effect was only found for the post-storage results and not the post-shelf life results. For the post-shelf life results of the 'African Rose' the GA_3 illustrated a quadratic effect with the 200 mg L^{-1} application increasing the percentage internal browning by 5% compared to the control, but as the rate was increased further the percentage internal browning decreased again to the same level as that of the control. In 'Laetitia', 'Larry Ann' and 'Pioneer' no biologically significant effects were found in post storage internal browning, gel breakdown or decay. Only after shelf life did 'African Rose' displayed a slight increase in gel breakdown in GA_3 treated fruit. For post-shelf life results of 'Pioneer' the 200 mg L^{-1} GA_{4+7} application decreased the internal browning by 8% compared to the control but this was not significant (P=0.2550). The contrast between the two GAs applied did however differ significantly and a quadratic effect was found for the GA_{4+7} applied. Why we found little or no effect on storage quality compared to previous research is unknown, but probably due to a smaller effect on fruit maturity as shown by the fruit firmness.

Effect on return bloom and hand thinning in the season after application

The application of GA_3 increased the percentage of vegetative buds on spurs significantly compared to the control and the GA_{4+7} application in 'Laetitia', while in 'Larry Ann', the GA_3 and GA_{4+7} applications both significantly increased the percentage of vegetative buds on short shoots, but not on spurs. Coetzee and Theron (1999) also found an increase in the number of vegetative buds in 'Sunlite' nectarine when GA_3 was applied four weeks before harvest. In 'Larry Ann' the percentage of reproductive buds on short shoots containing only one flower was significantly lowered by the GA_{4+7} application, compared to the control and the GA_3 application. On spurs, the percentage of reproductive buds containing three flowers was significantly higher following the GA_3 and GA_{4+7} applications compared to the control. It could therefore be said that the weaker flowers (flower buds containing one flower) was reduced by the GA-applications, but no effect was found on the flower buds containing more than two flowers. For 'Pioneer' and 'African Rose' the flower density was reduced compared to the control and more so by GA_3 application than GA_{4+7} and this decrease became more pronounced with an increase in GA concentration. In 'Pioneer' both the increase in vegetative buds and decrease in single-flower buds and reduced flower density points towards a reduction in return bloom, which was the aim of the GA applications. This reduction in the number of flowers was also found by Coetzee and Theron (1999) for GA_3, but without a concentration effect. Southwick and Fritts (1995) found a decrease in the number of flowers per tree applying GA (Release®LC) to 'Patterson' apricot, 'Black Amber' Japanese plum and 'May Fire' nectarine.

There was no reduction in the time required to thin or the number of fruitlets removed in 'Laetitia'; however, a reduction in the hand thinning time (23.4 and 31.3%, for GA_3 and GA_{4+7} respectively) and number of fruitlets removed was found in 'Larry Ann'. In 'African Rose' the GA_3 and GA_{4+7} applications reduced the time required to thin by an average of 28 and 19%, respectively. No difference was found between the effect of the GA_3 and GA_{4+7}, although the GA_3 reduced the time required and number of fruitlets removed, linearly with an increase in concentration. Coetzee and Theron (1999) found no effect of concentration of GA_3 on the number of fruitlets removed in nectarine with increasing concentration from 90 to 180 mg L^{-1}. González-Rossia et al. (2006) found that 50 mg L^{-1} GA_3 applied to 'Black Gold' and 'Black Diamond', reduced the number of flowers by 31 - 43%, resulting in a reduced hand thinning time of 45 and 47%, respectively.

The influence of GA_3 compared to the GA_{4+7} on the flower density was greater in 'Laetitia', 'Pioneer' and 'African Rose', but did not differ significantly in 'Larry Ann'. The same effect was found for the time required to thin and therefore, it would seem that GA_3 is a more reliable chemical bloom thinner than the GA_{4+7}, when applied at pit hardening, and that if a higher reduction in the flower density is required, the concentration could be increased. This difference between the two GAs was also found by Lenahan et al. (2006) in 'Bing' sweet cherries. The application of GA to successfully reduce the flower density would be dependent on the cultivar being treated. Hehnen et al. (2012) found that the effectiveness of chemical thinners is dependent on the weather conditions, flower dynamics and tree age.

Effect on yield efficiency and fruit quality in the season after application

Yield efficiency in the season following GA application was not reduced in 'Larry Ann' and 'Laetitia' despite the significant reduction in return bloom and the time required to thin. Contrary to this, González-Rossia et al. (2007) found a reduction in yield of peach and nectarine trees when the concentration of GA_3 reached 100 mg L^{-1} or higher. They reduced the time required to thin by approximately 50% and in nectarine, GA_3 at 50 mg L^{-1} or higher concentration had 6.0-7.0 fruit per metre shoot length after hand thinning compared to the 8.8 fruit per metre shoot length of the control (González-Rossia et al. 2007). With this reduction in the yield, a 16% increase was found in fruit weight (González-Rossia et al. 2007). Coetzee and Theron (1999) also found a reduction in the yield in 'Sunlite' nectarine at concentrations of 90, 120, 150 and 180 mg L^{-1} GA_3. They found no increase in the average size of fruit, but the percentage of fruit in the large fruit class was increased (Coetzee and Theron 1999). In our trials the reduction in time required to thin 'Laetitia' was 8 and 15% for the GA_3 and GA_{4+7} 100 mg L^{-1} applications, respectively and 25 and 31% in 'Larry Ann'. The reduction in the yield efficiency was therefore not as high as compared to González-Rossia et al. (2007) and as a consequence, no reduction in the yield was found. No reduction in yield was found, because the time required for thinning was only slightly reduced and therefore the number of fruit left after thinning was left unchanged by the treatments compared to the control. Because there was no reduction in yield, we found no significant increase in the mean fruit size in 'Larry Ann' and 'Laetitia', but this could also be because we only determined mean fruit size and not fruit size distribution.

Fruit firmness was consistently increased in 'Laetitia' and 'Larry Ann' by the GA_{4+7} compared to the GA_3 application and the control at harvest, post-storage and post-shelf life. This is due to GA_3 and GA_{4+7} again being applied at pit hardening in this season. The increased fruit firmness could therefore be a consequence of the application of GA to the fruit at pit hardening or because of the reduction of the number of flower, and therefore fruitlets through application of GA in the previous growing season. González-Rossia et al. (2006) found that applying 75 mg L-^{1} GA_3 increased the fruit firmness in 'Black Gold' Japanese plum at harvest, but the yield was decreased.

The applications of 50 mg L^{-1} GA over two consecutive seasons to 'Patterson' apricots reduced the flowering by 50% for both seasons (Southwick and Glozer 2000). In 'Laetitia' this was not found, and bloom density, time required to hand thin and number of fruitlets removed, were not significantly decreased in the spring of the 2013/2014 season. This could have been because the GA-application was not close enough to pit hardening during the 2013 season and therefore less effective, or that the fact that the sensitivity of cultivars to GA-applications differs (Hehnen et al. 2012).

Conclusion

The effect of GA-applications on the fruit size and quality, the return bloom and yield, and the fruit size and quality for the following season, was inconsistent. The reduction in return bloom along with the reduction in time required to hand thin showed promising results, especially when applying GA_3 at 100 mg L^{-1} or higher concentrations. The increase in fruit firmness will have a positive effect on the post-storage and -shelf life results, but the inconsistency of the results will restrain the usage of the two products.

References

Baugher TA, Schupp J, Miller S, Harsh M, Lesser K, Reichard K, Sollenberger E, Armand M, Kammerer L, Reid M, Rice L, Waybright S, Wenk B, Tindall M, Moore E. 2008. Chemical and mechanical thinning of peaches. *Pennsylvania Fruit News* 88: 16-17.

Coetzee JH, Theron KI. 1999. 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 on 'Sunlite' nectarines. *Journal of South African Society of Horticultural Sciences* 9(1): 13-17.

Crisosto CH, Johnson RS, de Jong T. 1997. Orchard factors affecting postharvest stone fruit quality. *HortScience* 32: 820- 823.

Day KR, de Jong TM. 1998. Improving fruit size: Thinning and girdling nectarines, peaches, and plums. *Curso Internacional de Fruticultura de Clima Templado-Frio, Mendoza, Argentina*.

González-Rossia D, Reig C, Juan M, Agustí M. 2006. The inhibition of flowering by means of gibberellic acid application reduces the cost of hand thinning in Japanese plums (*Prunus salicina* Lindl.). *Scientia Horticulturae* 110: 319-323.

González-Rossia D, Reig C, Juan M, Agustí M, 2007. Horticultural factors regulating effectiveness of GA_3 inhibiting flowering in peaches and nectarines (*Prunus persica* L. Batsch). *Scientia Horticulturae* 111: 352-357.

Hehnen D, Hanrahan I, Lewis K, Mcferson J, Blanke M. 2012. Mechanical flower thinning improves fruit quality of apples and promotes consistent bearing. *Scientia Horticulturae* 134: 241-244.

Lenahan OM, Whiting MD, Elfving DC. 2006. Gibberellic acid inhibits floral bud induction and improves 'Bing' sweet cherry fruit quality. *HortScience* 41(3): 654-659.

Lurie S. 2010. Plant growth regulators for improving postharvest stone fruit quality. *Acta Horticulturae* 884: 189-198.

Schupp JR, Baugher TA, Miller SS, Harsh RM, Lesser KM. 2008. Mechanical thinning of peach and apple trees reduces labor input and increases fruit size. *HortTechnology* 18(4): 660- 670.

Singh SP, Singh Z. 2013. Postharvest cold storage-induced oxidative stress in Japanese plums (*Prunus salicina* Lindl. Cv. Amber Jewel) in relation to harvest maturity. *Australian Journal of Crop Science* 7(3): 391-400.

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

Southwick SM, Fritts Jr, R. 1995. Commercial chemical thinning of stone fruit in California by gibberellins to reduce flowering. *Acta Horticulturae* 394: 135-147.

Southwick SM, Yeage JT, Zhou H. 1995. Flowering and fruiting in 'Patterson' apricot (*Prunus armeniaca*) in response to postharvest application of gibberellic acid. *Scientia Horticulturae* 60: 267-277.

Webster AD, Spencer JE, 2000. Fruit thinning plums and apricots. *Plant Growth Regulation* 31: 101-112.

Table 1: Summary of the orchard history for 'Laetitia', 'Larry Ann', 'Pioneer' and 'African Rose'.

Cultivar	Previous yield (ton Ha^{-1})
'Laetitia'	22
'Larry Ann'	43
'Pioneer'	22
'African Rose'	8

Table 2: Summary of the time of pit hardening, harvest, full bloom (score) and the fruitlets hand thinning for 'Laetitia', 'Larry Ann', 'Pioneer' and 'African Rose'.

Phenological stage	2011/2012	2012/2013
	'Laetitia'	
Pit hardening	16 November 2011	15 November 2012
Harvest	31 January 2012, 09 February 2012	28 January 2013, 05 February 2013
Full bloom: Bloom scored	15 September 2012	18 September 2013
Fruitlet hand thinning	31 October 2012	5 November 2013
	'Larry Ann'	
Pit hardening	16 November 2011	15 November 2012
Harvest	16 February 2012	13 February 2013
Fruitlet hand thinning	31 October 2012	
	'Pioneer'	
Pit hardening		17 October 2012
Harvest		26, 28 November 2012
Full bloom: Bloom scored		15 August 2013
Fruitlet hand thinning		27 September 2013
	'African Rose'	
Pit hardening		16 October 2012
Harvest		19, 20, 21 November 2012
Full bloom: Bloom scored		8 August 2013
Fruitlet hand thinning		24 September 2013

Table 3: The effect of GA-applications on the yield efficiency and the percentage of harvest picked per harvest date in 'Laetitia' and 'Larry Ann' in the season of GA-application (2011/2012).

	'Laetitia'								'Larry Ann'	
Treatment	Yield efficiency per tree(kg cm^{-2}) at first harvest and percentage of total harvest		Yield efficiency per tree(kg cm^{-2}) at second harvest and percentage of total harvest		Yield efficiency per tree(kg cm^{-2}) at third harvest and percentage of total harvest		Total yield efficiency per tree (kg cm^{-2})	Ton (ton ha^{-1})	Total yield efficiency per tree (kg cm^{-2})	Ton (ton ha^{-1})
	kg cm^{-2}	%	kg cm^{-2}	%	kg cm^{-2}	%				
Control (N-S)	0.037 ^{NS}	14.5	0.181 ^{NS}	70.7	0.038 ^{NS}	14.8	0.256 ^{NS}	57.3	0.166 ^{NS}	27.7
GA_3 100 mg L^{-1}	0.041	16.3	0.170	67.4	0.040	15.9	0.252	50.8	0.174	28.5
GA_{4+7} 100 mg L^{-1}	0.032	12.2	0.172	56.4	0.059	22.4	0.263	60.5	0.202	31.3
Significance level	*0.3337*		*0.8595*		*0.2221*		*0.8751*		*0.2874*	

^{NS} non-significant; *(N-S) non-sprayed

Table 4: The effect of GA-applications on the yield efficiency and the percentage of harvest picked per harvest date in 'Pioneer' in the season of GA-application (2012/2013).

Treatment	Yield efficiency per tree(kg cm^{-2}) at first harvest and percentage of total harvest		Yield efficiency per tree(kg cm^{-2}) at second harvest and percentage of total harvest		Total yield efficiency per tree (kg cm^{-2})	Ton (ton ha^{-1})
	kg cm^{-2}	%	kg cm^{-2}	%		
Control (non-sprayed)	0.048 ^{NS}	40.3	0.071 ^{NS}	59.7	0.119 ^{NS}	24.0
GA_3 100 mg L^{-1}	0.042	34.1	0.081	65.9	0.123	26.1
GA_3 200 mg L^{-1}	0.062	50.0	0.062	50.0	0.124	26.1
GA_3 400 mg L^{-1}	0.061	47.3	0.068	52.7	0.129	25.8
GA_{4+7} 100 mg L^{-1}	0.047	37.6	0.078	62.4	0.125	27.6
GA_{4+7} 200 mg L^{-1}	0.045	36.9	0.076	62.3	0.122	27.0
GA_{4+7} 400 mg L^{-1}	0.054	43.9	0.069	56.1	0.123	26.1
Significance level	*0.6328*		*0.7551*		*0.9926*	
*Significance level (C vs T)**	*0.6934*		*0.8680*		*0.5662*	
*Significance level (T vs T)***	*0.4085*		*0.5806*		*0.7556*	
Significance level (Lin)	*0.1808*		*0.2661*		*0.7716*	
Significance level (Quad)	*0.5534*		*0.3862*		*0.8050*	
Significance level (Int Lin)	*0.7042*		*0.9876*		*0.6822*	
Significance level (Int Quad)	*0.2888*		*0.3135*		*0.9190*	

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; ^{NS} non-significant

Table 5: The effect of GA-applications on the yield efficiency and the percentage of harvest picked per harvest date in 'African Rose' in the season of application (2012/2013).

Treatment	Yield efficiency per tree(kg cm^{-2}) at second harvest and percentage of total harvest			Yield efficiency per tree(kg cm^{-2}) at third harvest and percentage of total harvest			Yield efficiency per tree(kg cm^{-2}) at fourth harvest and percentage of total harvest			Total yield efficiency per tree (kg cm^{-2})		Ton (ton ha^{-1})
	kg cm^{-2}		%	kg cm^{-2}		%	kg cm^{-2}		%			
Control (non-sprayed)	0.032	a	28.3	0.033	NS	29.2	0.048	c	42.5	0.113	abc	14.2
GA_3 100 mg L^{-1}	0.018	bc	16.7	0.021		19.4	0.069	a	63.9	0.108	abc	13.2
GA_3 200 mg L^{-1}	0.021	abc	17.8	0.037		31.4	0.063	ab	53.4	0.118	a	12.6
GA_3 400 mg L^{-1}	0.016	bc	19.5	0.021		25.6	0.048	bc	58.5	0.082	d	13.7
GA_{4+7} 100 mg L^{-1}	0.014	c	14.4	0.023		23.7	0.062	abc	36.9	0.097	bdc	12.2
GA_{4+7} 200 mg L^{-1}	0.013	c	13.7	0.017		17.9	0.064	a	37.4	0.095	cd	10.4
GA_{4+7} 400 mg L^{-1}	0.027	ab	23.7	0.025		21.9	0.062	abc	54.4	0.114	ab	15.1
Significance level	*0.0212*			*0.0678*			*0.0452*			*0.0039*		
*Significance level (C vs T)**	*0.0032*			*0.0731*			*0.0220*			*0.1612*		
*Significance level (T vs T)***	*0.9304*			*0.3309*			*0.5634*			*0.9456*		
Significance level (Lin)	*0.2852*			*0.9540*			*0.0463*			*0.3713*		
Significance level (Quad)	*0.9161*			*0.3021*			*0.7431*			*0.3938*		
Significance level (Int Lin)	*0.0480*			*0.3449*			*0.0569*			*0.0006*		
Significance level (Int Quad)	*0.2064*			*0.0130*			*0.9243*			*0.0285*		

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; [NS] non-significant

Table 6: The effect of GA-application on the fruit weight, length and diameter in the season of GA-application in 'Laetitia' (2011/2012).

Treatment	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)
Control (non-sprayed)	58.1 ^{NS}	45.5 ^{NS}	43.5 ^{NS}
GA_3 100 mg L^{-1}	56.1	42.9	41.4
GA_{4+7} 100 mg L^{-1}	59.5	43.9	41.8
Significance level	*0.7891*	*0.7452*	*0.7898*

^{NS} non-significant

Table 7: The effect of GA-application on the fruit weight, length and diameter in the season of GA-application in 'Larry Ann' (2011/2012).

Treatment	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)
Control (non-sprayed)	103.5 ^{NS}	52.8 ^{NS}	57.0 ^{NS}
GA_3 100 mg L^{-1}	105.2	53.2	57.4
GA_{4+7} 100 mg L^{-1}	100.0	52.0	56.5
Significance level	*0.4854*	*0.2761*	*0.6398*

^{NS} non-significant

Table 8: The effect of GA-application on the fruit weight, length and diameter in the season of GA-application in 'Pioneer' (2012/2013).

Treatment	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)
Control (non-sprayed)	55.1 NS	42.4 NS	46.5 NS
GA_3 100 mg L^{-1}	56.3	42.4	46.8
GA_3 200 mg L^{-1}	55.1	42.2	46.2
GA_3 400 mg L^{-1}	57.1	42.8	46.9
GA_{4+7} 100 mg L^{-1}	54.2	40.7	46.1
GA_{4+7} 200 mg L^{-1}	57.4	42.8	47.0
GA_{4+7} 400 mg L^{-1}	54.6	42.3	46.1
Significance level	*0.5444*	*0.2474*	*0.4867*
*Significance level (C vs T)**	*0.6598*	*0.7386*	*0.9244*
*Significance level (T vs T)***	*0.5167*	*0.3077*	*0.4295*
Significance level (Lin)	*0.7547*	*0.1472*	*0.9913*
Significance level (Quad)	*0.5105*	*0.2610*	*0.6746*
Significance level (Int Lin)	*0.5806*	*0.4982*	*0.6160*
Significance level (Int Quad)	*0.0641*	*0.0854*	*0.0394*

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; NS non-significant

Table 9: The effect of GA-application on the fruit weight, length and diameter in the season of GA-application in 'African Rose' (2012/2013).

Treatment	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)
Control (non-sprayed)	72.0 ^{NS}	45.0 ^{NS}	50.3 ^{NS}
GA_3 100 mg L^{-1}	75.1	45.6	51.4
GA_3 200 mg L^{-1}	67.1	42.5	47.9
GA_3 400 mg L^{-1}	69.2	44.5	50.1
GA_{4+7} 100 mg L^{-1}	67.0	42.5	47.9
GA_{4+7} 200 mg L^{-1}	72.5	45.3	51.0
GA_{4+7} 400 mg L^{-1}	71.7	45.1	50.8
Significance level	*0.1662*	*0.2456*	*0.2536*
*Significance level (C vs T)**	*0.5397*	*0.5537*	*0.7492*
*Significance level (T vs T)***	*0.9885*	*0.8631*	*0.9305*
Significance level (Lin)	*0.8765*	*0.4532*	*0.4662*
Significance level (Quad)	*0.6169*	*0.7075*	*0.6373*
Significance level (Int Lin)	*0.0758*	*0.2226*	*0.2028*
Significance level (Int Quad)	*0.0212*	*0.0219*	*0.0223*

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; ^{NS} non-significant

Table 10: The effect of GA-application on the fruit firmness and TSS of the season of GA-application in 'Laetitia' and 'Larry Ann' (2011/2012).

Treatment	Laetitia		Larry Ann	
	Fruit firmness (kg)	TSS (%)*	Fruit firmness (kg)	TSS (%)*
Control (non-sprayed)	7.0 NS	10.42 NS	8.9 b	15.45 NS
GA_3 100 mg L^{-1}	6.4	9.89	9.5 ab	15.48
GA_{4+7} 100 mg L^{-1}	6.8	9.79	10.0 a	15.58
Significance level	*0.5244*	*0.7175*	*0.0090*	*0.9165*

NS non-significant; *Total soluble solids concentration

Table 11: The effect of GA-application on the fruit firmness, percentage split pit and TSS of the season of GA-application in 'Pioneer' and 'African Rose' (2012/2013).

Treatment	Pioneer					African Rose		
	Fruit firmness (kg)		Split pit	TSS (%)*		Fruit firmness (kg)	Split pit	TSS (%)*
Control (non-sprayed)	7.8	c	3 NS	11.21	a	5.1 NS	0 NS	11.10 NS
GA_3 100 mg L^{-1}	7.7	c	1	11.17	a	5.6	0	11.54
GA_3 200 mg L^{-1}	8.4	bc	2	11.15	ab	5.2	0	10.83
GA_3 400 mg L^{-1}	8.7	b	0	10.62	b	5.8	0	10.92
GA_{4+7} 100 mg L^{-1}	8.9	ab	2	11.43	a	5.7	0	11.20
GA_{4+7} 200 mg L^{-1}	9.4	a	2	11.39	a	5.9	0	11.76
GA_{4+7} 400 mg L^{-1}	8.9	ab	1	11.67	a	5.5	0	12.07
Significance level	*0.0001*		*0.6604*	*0.0164*		*0.1347*	*0.4350*	*0.4400*
*Significance level (C vs T)**	*0.0030*		*0.3431*	*0.8846*		*0.0338*	*0.6847*	*0.5691*
*Significance level (T vs T)***	*0.0003*		*0.3316*	*0.0018*		*0.3415*	*0.2849*	*0.1295*
Significance level (Lin)	*0.1478*		*0.2763*	*0.4008*		*0.9919*	*0.2533*	*0.7422*
Significance level (Quad)	*0.0605*		*0.4153*	*0.9054*		*0.6949*	*0.3218*	*0.7701*
Significance level (Int Lin)	*0.0624*		*0.7812*	*0.0282*		*0.2829*	*0.2533*	*0.1472*
Significance level (Int Quad)	*0.8168*		*0.5924*	*0.4096*		*0.0745*	*0.3218*	*0.3479*

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; NS non-significant; *Total soluble solids concentration

Table 12: The effects of GA-application on the post-storage fruit quality, of the season of GA-application, determined by fruit firmness, percentage shrivel, decay, gel breakdown, internal browning and split pit for 'Laetitia' (2011/2012).

Treatment	Fruit firmness (kg)	Percentage shrivel	Percentage decay	Percentage gel breakdown	Percentage internal browning	Percentage split pit
Control (non-sprayed)	4.9 NS	9 NS	0 NS	2 NS	5 NS	.
GA_3 100 mg L^{-1}	4.8	6	0	3	4	.
GA_{4+7} 100 mg L^{-1}	4.8	6	1	2	4	.
Significance level	*0.9254*	*0.3379*	*0.2078*	*0.7422*	*0.9152*	.

NS non-significant

Table 13: The effects of GA-application on the post-storage fruit quality, of the season of GA-application, determined by fruit firmness, percentage shrivel, decay, gel breakdown, internal browning and split pit for 'Larry Ann' (2011/2012).

Treatment	Fruit firmness (kg)	Percentage shrivel	Percentage decay	Percentage gel breakdown	Percentage internal browning	Percentage split pit
Control (non-sprayed)	6.2 b	.	0 NS	2 NS	.	0 NS
GA_3 100 mg L^{-1}	7.7 a	.	0	2	.	1
GA_{4+7} 100 mg L^{-1}	7.4 a	.	1	0	.	0
Significance level	*0.0021*	.	*0.3874*	*0.3874*	.	*0.3874*

NS non-significant

Table 14: The effects of GA-application on the post-storage fruit quality, of the season of GA-application, determined by fruit firmness, percentage shrivel, decay, gel breakdown, internal browning and split pit for 'Pioneer' (2012/2013).

Treatment	Fruit firmness (kg)		Percentage shrivel	Percentage decay	Percentage split pit	Percentage internal browning	Percentage gel breakdown
Control (non-sprayed)	6.2	b	1 NS	0 NS	3 NS	1 NS	0 NS
GA_3 100 mg L^{-1}	5.9	b	1	0	5	1	2
GA_3 200 mg L^{-1}	6.1	b	0	1	1	2	1
GA_3 400 mg L^{-1}	6.1	b	0	2	2	0	0
GA_{4+7} 100 mg L^{-1}	6.1	b	0	0	3	2	1
GA_{4+7} 200 mg L^{-1}	7.2	a	3	1	2	0	0
GA_{4+7} 400 mg L^{-1}	6.4	b	0	0	3	1	2
Significance level	*<0.0001*		*0.1006*	*0.7985*	*0.4131*	*0.2995*	*0.1044*
*Significance level (C vs T)**	*0.5313*		*0.3795*	*0.6382*	*0.7479*	*0.9510*	*0.3174*
*Significance level (T vs T)***	*0.0022*		*0.5584*	*0.4251*	*0.8835*	*0.6108*	*0.2169*
Significance level (Lin)	*0.6045*		*0.9494*	*0.3199*	*0.7384*	*0.2246*	*0.8892*
Significance level (Quad)	*0.0030*		*0.1384*	*0.7997*	*0.0775*	*0.8415*	*0.0876*
Significance level (Int Lin)	*0.7405*		*0.4582*	*0.3083*	*0.2331*	*0.8396*	*0.0255*
Significance level (Int Quad)	*0.0299*		*0.0090*	*0.8119*	*0.2634*	*0.0216*	*0.5783*

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; ^{NS} non-significant

Table 15: The effects of GA-application on the post-storage fruit quality, of the season of GA-application, determined by fruit firmness, percentage shrivel, decay, gel breakdown, internal browning and split pit for ‘African Rose’ (2012/2013).

Treatment	Fruit firmness (kg)		Percentage shrivel	Percentage gel breakdown	Percentage split pit	Percentage internal browning		Percentage decay
Control (non-sprayed)	4.0	d	10 NS	0 NS	0 NS	7	ab	2 NS
GA_3 100 mg L^{-1}	4.7	bc	6	0	0	5	bc	1
GA_3 200 mg L^{-1}	4.5	c	4	0	0	12	a	1
GA_3 400 mg L^{-1}	5.1	ab	3	0	0	7	ab	1
GA_{4+7} 100 mg L^{-1}	5.4	a	8	0	0	1	c	2
GA_{4+7} 200 mg L^{-1}	5.0	abc	3	1	1	6	bc	3
GA_{4+7} 400 mg L^{-1}	5.0	bc	7	0	2	9	ab	3
Significance level	*<0.0001*		*0.1258*	*0.5630*	*0.0571*	*0.0314*		*0.1192*
*Significance level (C vs T)**	*<0.0001*		*0.0200*	*0.7114*	*0.5293*	*0.4390*		*0.7238*
*Significance level (T vs T)***	*0.0580*		*0.3338*	*0.1835*	*0.0355*	*0.1359*		*0.1386*
Significance level (Lin)	*0.7500*		*0.5812*	*0.5512*	*0.0517*	*0.0538*		*0.4553*
Significance level (Quad)	*0.0628*		*0.1016*	*0.0281*	*0.9354*	*0.0251*		*0.4867*
Significance level (Int Lin)	*0.0046*		*0.8281*	*0.7024*	*0.0702*	*0.1422*		*0.5078*
Significance level (Int Quad)	*0.6107*		*0.3351*	*0.1242*	*0.9200*	*0.1900*		*0.3837*

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; NS non-significant

Table 16: The effects of GA-application on the post-shelf life fruit quality, of the season of GA-application, determined by fruit firmness, percentage shrivel, decay, gel breakdown, internal browning and split pit for 'Laetitia' (2011/2012).

Treatment	Fruit firmness (kg)	Percentage shrivel	Percentage decay	Percentage gel breakdown	Percentage internal browning	Percentage split pit
Control (non-sprayed)	2.620 NS	11 NS	0 NS	10 NS	2 b	.
GA_3 100 mg L^{-1}	2.634	7	0	17	6 a	.
GA_{4+7} 100 mg L^{-1}	2.627	7	0	15	0 b	.
Significance level	*0.9985*	*0.0776*	*0.6166*	*0.3613*	*0.0065*	

NS non-significant

Table 17: The effects of GA-application on the post-shelf life fruit quality, of the season of GA-application, determined by fruit firmness, percentage shrivel, decay, gel breakdown, internal browning and split pit for 'Larry Ann' (2011/2012).

Treatment	Fruit firmness (kg)	Percentage shrivel	Percentage decay	Percentage gel breakdown	Percentage internal browning	Percentage split pit
Control (non-sprayed)	4.6 b	0 NS	2 NS	.	1 NS	.
GA_3 100 mg L^{-1}	5.8 a	0	2	.	0	.
GA_{4+7} 100 mg L^{-1}	5.4 ab	2	1	.	1	.
Significance level	*0.0425*	*0.1342*	*0.8337*	.	*0.6302*	.

NS non-significant

Table 18: The effects of GA-application on the post-shelf life fruit quality, of the season of GA-application, determined by fruit firmness, percentage shrivel, decay, gel breakdown, internal browning and split pit for 'Pioneers' (2012/2013).

Treatment	Fruit firmness (kg)		Percentage shrivel	Percentage decay	Percentage split pit	Percentage internal browning		Percentage gel breakdown
Control (non-sprayed)	3.6	b	3 NS	0 NS	3 NS	10	ab	14 NS
GA_3 100 mg L^{-1}	3.5	b	1	2	7	10	ab	24
GA_3 200 mg L^{-1}	3.8	b	4	1	7	13	a	17
GA_3 400 mg L^{-1}	3.7	b	2	1	5	3	bc	26
GA_{4+7} 100 mg L^{-1}	4.1	ab	1	1	4	6	bc	25
GA_{4+7} 200 mg L^{-1}	4.8	a	4	0	6	2	c	17
GA_{4+7} 400 mg L^{-1}	3.7	b	4	1	2	7	abc	23
Significance level	0.0170		0.3888	0.1693	0.2976	0.0476		0.0860
*Significance level (C vs T)**	0.2223		0.9954	0.1078	0.2699	0.2550		0.0298
*Significance level (T vs T)***	0.0168		0.6231	0.1894	0.1023	0.0725		0.8688
Significance level (Lin)	0.4210		0.1661	0.8391	0.3024	0.2601		0.6713
Significance level (Quad)	0.0249		0.0941	0.0602	0.1751	0.7095		0.0158
Significance level (Int Lin)	0.1876		0.2537	0.4061	0.8384	0.0700		0.5148
Significance level (Int Quad)	*0.1832*		*0.9785*	*0.4263*	*0.5012*	*0.0438*		*0.9597*

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; ^{NS} non-significant

Table 19: The effects of GA-application on the post-shelf life fruit quality, of the season of GA-application, determined by fruit firmness, percentage shrivel, decay, gel breakdown, internal browning and split pit for 'African Rose' (2012/2013).

Treatment	Fruit firmness (kg)	Percentage shrivel	Percentage decay	Percentage split pit	Percentage internal browning	Percentage gel breakdown	Percentage air-rated fruit
Control (non-sprayed)	3.0 d	13 NS	3 NS	0 NS	7 NS	8 c	39 NS
GA_3 100 mg L^{-1}	3.3 cd	8	1	2	5	16 bc	31
GA_3 200 mg L^{-1}	3.2 d	9	3	1	11	19 ab	40
GA_3 400 mg L^{-1}	3.8 bc	7	1	4	12	25 a	41
GA_{4+7} 100 mg L^{-1}	4.4 a	13	2	5	6	13 bc	42
GA_{4+7} 200 mg L^{-1}	4.6 a	9	2	4	4	1 c	33
GA_{4+7} 400 mg L^{-1}	4.1 ab	13	0	2	3	11 bc	46
Significance level	*<0.0001*	*0.5486*	*0.5830*	*0.2662*	*0.1363*	*0.0035*	*0.1437*
*Significance level (C vs T)**	*<0.0001*	*0.2717*	*0.3206*	*0.1221*	*0.8699*	*0.0262*	*0.7215*
*Significance level (T vs T)***	*<0.0001*	*0.1227*	*0.7511*	*0.4355*	*0.0253*	*0.0006*	*0.3044*
Significance level (Lin)	*0.6211*	*0.9807*	*0.2425*	*0.9340*	*0.4563*	*0.2198*	*0.0728*
Significance level (Quad)	*0.7839*	*0.5024*	*0.2616*	*0.4590*	*0.4859*	*0.7138*	*0.5633*
Significance level (Int Lin)	*0.0119*	*0.7192*	*0.5998*	*0.0516*	*0.0907*	*0.0962*	*0.9114*
Significance level (Int Quad)	*0.0467*	*0.3928*	*0.3996*	*0.5358*	*0.2651*	*0.6187*	*0.0332*

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; NS non-significant

Table 200: The effect of GA-application on the return bloom, as indicated by the number of vegetative buds, reproductive buds containing one, two or three flowers on short shoots and spurs of 'Laetitia' (2012/2013).

Treatment	Number of vegetative buds on short shoots (< 15 cm)	Number of reproductive buds containing one flower on short shoots	Number of reproductive buds containing two flowers on short shoots	Number of reproductive buds containing three flowers on short shoots	Number of vegetative buds on a spur	Number of reproductive buds containing one flower on a spur	Number of reproductive buds containing two flowers on a spur	Number of reproductive buds containing three flowers on a spur
Control (N-S)	37.8^{NS}	14.2 ^{NS}	46.7 ^{NS}	1.2 ^{NS}	28.7 b	19.4 ^{NS}	50.3 ^{NS}	1.6 ^{NS}
GA_3 100 mg L^{-1}	41.6	13.2	39.0	2.9	39.3 a	17.1	47.6	1.6
GA_{4+7} 100 mg L^{-1}	42.2	12.5	42.4	2.9	31.3 b	17.2	58.0	2.3
Significance level	*0.4461*	*0.8119*	*0.1087*	*0.4897*	*0.0055*	*0.7475*	*0.3246*	*0.7495*

^{NS} non-significant; *(N-S) non-sprayed

Table 21: The effect of GA-application on the return bloom, as indicated by the number of vegetative buds, reproductive buds containing one, two or three flowers on short shoots and spurs of 'Larry Ann' (2012/2013).

Treatment	Amount of vegetative buds on short shoots (< 15 cm)	Amount of reproductive buds containing one flower on short shoots	Amount of reproductive buds containing two flowers on short shoots	Amount of reproductive buds containing three flowers on short shoots	Amount of vegetative buds on a spur	Amount of reproductive buds containing one flower on a spur	Amount of reproductive buds containing two flowers on a spur	Amount of reproductive buds containing three flowers on a spur
Control(N-S)*	28.5 b	14.5 a	48.5 ^{NS}	5.2 ^{NS}	22.7 ^{NS}	17.8 ^{NS}	54.2 ^{NS}	5.3 b
GA_3 100 mg L^{-1}	38.9 a	13.5 a	43.0	4.5	28.1	16.3	50.5	8.8 a
GA_{4+7} 100 mg L^{-1}	41.9 a	10.2 b	41.9	5.9	28.6	15.7	57.1	9.4 a
Significance level	*0.0284*	*0.0030*	*0.2488*	*0.6389*	*0.0976*	*0.8222*	*0.6297*	*0.0123*

^{NS} non-significant; *(N-S) non-sprayed

Table 22: The effect of GA-application on the time required to thin and the number of fruitlets removed for 'Laetitia' (2012/2013).

Treatment	Hand thinning time per tree (min)	Number of fruitlets removed per tree
Control (non-sprayed)	6.2 ^{NS}	513 ^{NS}
GA_3 100 mg L^{-1}	5.7	346
GA_{4+7} 100 mg L^{-1}	5.3	389
Significance level	*0.4235*	*0.1066*

^{NS} non-significant

Table 23: The effect of GA-application on the time required to thin and the number of fruitlets removed for 'Larry Ann' (2012/2013).

Treatment	Hand thinning time per tree(min)	Number of fruitlets removed per tree
Control (non-sprayed)	6.7 b	574 b
GA_3 100 mg L^{-1}	5.0 a	376 a
GA_{4+7} 100 mg L^{-1}	4.6 a	378 a
Significance level	*0.0018*	0.0013

^{NS} non-significant

Table24: The effect of GA-application on the bloom score, time required to thin and the number of fruitlets removed for 'Laetitia' (2013/2014).

Treatment	Bloom score *	Hand thinning time per tree (min)	Number of fruitlets removed per tree
Control (non-sprayed)	2.4 [NS]	5.5 [NS]	383 [NS]
GA_3 100 mg L^{-1}	1.8	4.9	305
GA_{4+7} 100 mg L^{-1}	1.8	5.3	334
Significance level	0.1141	0.1625	0.6588

[NS] non-significant; *0-5 score, 5 – high and 0 - low

Table 25: The effect of GA-application on the flowers density scored at full bloom and the number of fruitlets on the tree before harvest 'Pioneer' (2013/2014).

Treatment	Bloom score ***		Number of fruitlets per tree
Control (non-sprayed)	5.7	a	191 [NS]
GA_3 100 mg L^{-1}	5.2	a	164
GA_3 200 mg L^{-1}	3.4	bc	158
GA_3 400 mg L^{-1}	1.3	d	150
GA_{4+7} 100 mg L^{-1}	5.7	a	210
GA_{4+7} 200 mg L^{-1}	4.0	b	154
GA_{4+7} 400 mg L^{-1}	2.7	c	184
Significance level	*<0.0001*		*0.1420*
*Significance level (C vs T)**	*<0.0001*		*0.2552*
*Significance level (T vs T)***	*0.0049*		*0.0796*
Significance level (Lin)	*<0.0001*		*0.3758*
Significance level (Quad)	*0.0651*		*0.1132*
Significance level (Int Lin)	*0.1606*		*0.9527*
Significance level (Int Quad)	*0.7322*		*0.1427*

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; [NS] non-significant; ***0-5 score, 5 – high and 0 - low

Table26: The effect of GA-application on the flower density scored at full bloom, the time required to thin and the number of fruitlets removed for 'African Rose' (2013/2014).

Treatment	Bloom score ***		Hand thinning time per tree (min)		Number of fruitlets removed per tree	
Control (non-sprayed)	6.4	a	10.0	a	882	a
GA_3 100 mg L^{-1}	4.7	bc	9.5	a	788	ab
GA_3 200 mg L^{-1}	3.4	d	6.9	bc	588	b
GA_3 400 mg L^{-1}	1.2	e	5.2	c	335	c
GA_{4+7} 100 mg L^{-1}	3.9	ab	8.9	ab	795	ab
GA_{4+7} 200 mg L^{-1}	3.8	cd	6.9	bc	636	b
GA_{4+7} 400 mg L^{-1}	3.0	d	8.4	ab	622	b
Significance level	*<0.0001*		*0.0013*		*0.0001*	
Significance level (C vs T)*	*<0.0001*		*0.0099*		*0.0027*	
Significance level (T vs T)**	*0.0014*		*0.1920*		*0.0713*	
Significance level (Lin)	*<0.0001*		*0.0119*		*0.0002*	
Significance level (Quad)	*0.0978*		*0.0504*		*0.2676*	
Significance level (Int Lin)	*0.0945*		*0.0174*		*0.0528*	
Significance level (Int Quad)	*0.2743*		*0.6831*		*0.6921*	

* Control vs. GA treatments; **GA_3 vs GA_{4+7}; ^{NS} non-significant; ***0-5 score, 5 – high and 0 - low

Table 27: The effect of GA-applications on the yield efficiency and the percentage of harvest harvested per harvest for 'Laetitia' and 'Larry Ann' (2012/2013).

	'Laetitia'						'Larry Ann'	
Treatment	Yield efficiency per tree(kg cm^{-2}) at first harvest and percentage harvested		Yield efficiency per tree(kg cm^{-2}) at second harvest and percentage harvested		Total yield efficiency per tree (kg cm^{-2})	Ton (ton ha^{-1})	Total yield efficiency per tree (kg cm^{-2})	Ton (ton ha^{-1})
	kg cm^{-2}	%	kg cm^{-2}	%				
Control (non-sprayed)	0.079 ^{NS}	50.0	0.079 ^{NS}	50.0	0.158 ^{NS}	33.6	0.317 ^{NS}	55.4
GA_3 100 mg L^{-1}	0.077	60.6	0.050	39.4	0.127	25.1	0.269	51.4
GA_{4+7} 100 mg L^{-1}	0.063	44.4	0.079	55.6	0.142	29.7	0.330	54.7
Significance level	*0.4368*		*0.1071*		*0.4858*		*0.1760*	

^{NS} non-significant

Table 28: The effect of GA-application on the fruit weight, length and diameter in the following season for 'Laetitia' (2012/2013).

Treatment	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)
Control (non-sprayed)	58.7 NS	45.8 NS	46.2 NS
GA_3 100 mg L^{-1}	60.6	46.4	46.7
GA_{4+7} 100 mg L^{-1}	62.9	46.7	47.5
Significance level	*0.4764*	*0.6242*	*0.3646*

NS non-significant

Table 29: The effect of GA-application on the fruit weight, length and diameter in the following season for 'Larry Ann' (2012/2013).

Treatment	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)
Control (non-sprayed)	93.1 NS	48.4 NS	56.4 NS
GA_3 100 mg L^{-1}	96.0	49.0	56.8
GA_{4+7} 100 mg L^{-1}	94.6	48.8	56.7
Significance level	*0.6452*	*0.3718*	*0.8526*

NS non-significant

Table 30: The effect of GA-application on fruit firmness, TSS, the percentage split pit and cracked fruit for 'Laetitia' and 'Larry Ann' (2012/2013).

	'Laetitia'			'Larry Ann'			
Treatment	Fruit firmness (kg)	TSS (%)*	Split pit	Fruit firmness (kg)	TSS (%)*	Fruit split	Split pit
Control (non-sprayed)	6.2 B	12.9 NS	0 NS	5.9 b	11.57 NS	2.3 NS	0.7 NS
GA_3 100 mg L^{-1}	6.0 b	13.2	1	6.1 b	11.70	1.7	0.0
GA_{4+7} 100 mg L^{-1}	7.1 a	13.2	2	7.2 a	11.19	3.0	1.3
Significance level	*0.0075*	*0.4346*	*0.2707*	*0.0003*	*0.5793*	*0.7089*	*0.3874*

NS non-significant; *Total soluble solids concentration

Table31: The effect of GA-applications on the post-storage fruit quality measured through fruit firmness, percentage internal browning, shrivel, gel breakdown, split pit and decay for 'Laetitia' (2012/2013).

Treatment	Fruit firmness (kg)	Percentage internal browning	Percentage shrivel	Percentage gel breakdown	Percentage split pit	Percentage decay
Control (non-sprayed)	3.4 b	0 [NS]	6 [NS]	3 [NS]	1 [NS]	0 [NS]
GA_3 100 mg L^{-1}	3.4 b	0	4	1	0	0
GA_{4+7} 100 mg L^{-1}	4.0 a	0	4	3	1	1
Significance level	*0.0037*	*0.3517*	*0.6010*	*0.4207*	*0.2889*	*0.2017*

[NS] non-significant

Table 32: The effect of GA-applications on the post-storage fruit quality measured through fruit firmness, percentage internal browning, shrivel, gel breakdown, split pit and decay for 'Larry Ann' (2012/2013).

Treatment	Fruit firmness (kg)	Percentage shrivel	Percentage decay	Percentage internal browning	Percentage gel breakdown	Percentage split pit
Control (non-sprayed)	4.8 b	2 [NS]	0 [NS]	0 [NS]	0 b	0 b
GA_3 100 mg L^{-1}	4.6 b	6	1	6	5 a	2 a
GA_{4+7} 100 mg L^{-1}	5.8 a	1	0	8	5 a	0 b
Significance level	*<0.0001*	*0.1132*	*0.3874*	*0.1059*	*0.0325*	*0.0404*

[NS] non-significant

Table 33: The effect of GA-applications on the post-shelf life fruit quality measured through fruit firmness, percentage internal browning, shrivel, gel breakdown, split pit and decay for 'Laetitia' (2012/2013).

Treatment	Fruit firmness (kg)	Percentage internal browning	Percentage shrivel	Percentage gel breakdown	Percentage split pit	Percentage decay
Control (non-sprayed)	2.4 b	.	10	6	0	1
GA_3 100 mg L^{-1}	2.3 b	.	6	3	1	0
GA_{4+7} 100 mg L^{-1}	2.7 a	.	9	6	0	1
Significance level	*0.0098*	.	*0.5370*	*0.3470*	*0.4764*	*0.3983*

[NS] non-significant

Table 34: The effect of GA-applications on the post-storage fruit quality measured through fruit firmness, percentage internal browning, shrivel, gel breakdown, split pit and decay for 'Larry Ann' (2012/2013).

Treatment	Fruit firmness (kg)	Percentage shrivel	Percentage decay	Percentage internal browning	Percentage gel breakdown	Percentage split pit
Control (non-sprayed)	3.8 b	3 [NS]	2 [NS]	6 [NS]	6 [NS]	2 [NS]
GA_3 100 mg L^{-1}	4.2 b	2	3	9	8	1
GA_{4+7} 100 mg L^{-1}	5.1 a	1	1	11	5	1
Significance level	*0.0006*	*0.6742*	*0.5204*	*0.1342*	*0.5313*	*0.1342*

[NS] non-significant

GENERAL CONCLUSION

In fruit production it is important to produce fruit of high quality and the appropriate size. This will ensure that the crop produced is economically sustainable. To produce fruit of high quality and the appropriate size, flower or fruitlet thinning needs to be performed timeously, as most fruit trees produce more flowers and set more fruit than is required for an economical and sustainable crop load. The higher quality includes an improvement in firmness, and higher sugar, phenol and vitamin C content. The fruit maturity is advanced, while the number of reproductive buds initiated increases, which leads to a better fruit-to-shoot ratio for the following season. Fewer fruit after thinning would also lead to the reduction in harvest cost and this saving coupled with the increase in fruit size and quality, would also give rise to an increase in profitability.

Having established the importance of thinning in stone fruit it however needs to be noted that thinning is still mostly performed by hand. This is a problem as hand thinning is labour intensive. Labour is becoming difficult to obtain and therefore the cost of labour is increasing. To optimise profit and perform thinning effectively, an alternative for hand thinning is needed. Two possible alternatives are mechanical and chemical thinning.

Our trials performed with the Darwin 300™ on nectarine (Paper 1) and Japanese plum (Paper 2) illustrated that mechanical bloom thinning has the potential to reduce the time required to hand thin at the fruitlet stage. In the case of the nectarines, the time required to thin the trees was significantly reduced by 37%. In the case of 'Zephyr', an increase in rotor speed resulted in a 50% decrease in the time required for thinning. The significant decrease in the time required for hand thinning was also illustrated for the plums where a decrease of 34% was found. The number of fruitlets removed by hand illustrated a bigger reduction in the hand thinning required at fruitlet stage, compared to the reduction in time required to thin after bloom thinning was performed with the Darwin 300™. This is because of the "ladder effect". The "ladder effect" is the time it takes the labourer to move the ladder between trees, climb up and down the ladder and empty his harvesting bag when thinning. This time cannot be reduced by using the Darwin 300™ and will make up a large proportion of the time required for hand thinning.

When a reduction in the time required for hand thinning was achieved, it also resulted in a reduction in the yield efficiency. For the nectarines the decrease in the yield efficiency was ± 22%, but for the plums this effect was not as large. The only cultivar that gave a significant reduction of 55% in yield efficiency was the African Delight. This reduction in the yield efficiency was probably partially due to the low and erratic fruit set percentage of the ‘African Delight’, rather than the thinning effect of the Darwin 300^{TM}.

Thinning during bloom, rather than at the fruitlet stage, plus the fact that the yield was reduced would lead to the increase in fruit size compared to the control. The “earlier” thinning effect was illustrated in the ‘Royal Sun’ where the increase in fruit size was the same for the mechanical thinning compared to the bloom thinned control. For the ‘Zephyr’ and ‘Summer Fire’ an increase in fruit size was also found, but this could be because of thinning performed earlier or because of the fact that the yield was reduced. For plum cultivars, the Laetitia and African Rose showed increases in fruit size. For these two cultivars the yield efficiency was not significantly decreased, therefore the increased fruit size was due to the majority of the thinning being performed at bloom rather than at the fruitlet stage. In general, the fruit quality was not increased in the nectarines and plums, but rather a decrease in the fruit quality was found as the rotor speeds was increased. Here a slight increase in fruit cracking and pit splitting was found for elevated rotor speeds.

The Darwin 300^{TM} could therefore be a tool for producers to use to reduce the need for hand thinning at the fruitlet stage and also have beneficial effects on fruit size and quality. The bloom thinner would result in the reduction of production costs and should increase the profit. It should always be remembered that as the rotor speed is increased, with a constant tractor speed, the need for hand thinning is reduced, but so too the yield. When the yield is reduced, the fruit size will be increased, but this could also have detrimental effects on the fruit quality. If the increase in fruit size is not wanted, the number of fruitlets left after thinning could be increased. Care should also be taken with cultivars that have problems with pit splitting or fruit cracking as the earlier thinning increases fruit growth, thereby stimulating more fruit cracking or splitting of pits. Thinning with the Darwin 300^{TM} is therefore dependent on the cultivar and the needs of the producer.

To optimise bloom thinning with the Darwin 300^{TM} changes has to be made to the orchard design and tree architecture. Firstly, the row surface needs to be smooth. If there is a ditch in the row, the tractor will dip into the tree, therefore over-thinning the tree and with the adjustment of the driver the next tree could be under-thinned. Secondly, raised beds will lower the efficiency of thinning with the Darwin 300^{TM}, as the tree are now higher than 3 meters from the tractor row surface. The top parts of the canopies of the trees would therefore not be thinned effectively. Thirdly, any scaffold branches pointing into the tractor row would result in under-thinning as the driver has to drive around such branches, thus not thinning the specific tree. The adjustment of pruning strategies to remove such branches would therefore be of value to the producer. Any shoots that are shorter than 15 cm can also be removed from the tree, because these shoots will not be thinned optimally. Tree architecture therefore needs to move to less complex training systems. Trees trained to a hedge are an example of a training system that is not complex and would therefore increase the efficiency of thinning with the Darwin 300™. Studies are also recommended looking at the effect of pruning strategies to assist the bloom thinning with the Darwin 300™. Future studies can also include performing thinning with the Darwin 300™ in combination with a mechanical platform for hand thinning at the fruitlet stage. This would remove the "ladder effect" referred to earlier and therefore reduce the time required to hand thin. Different hand thinning strategies could also be explored as the fruitlets are left at different positions after bloom thinning compared to fruitlet thinning only. This would therefore reduce the chance of over thinning occurring.

For the chemical thinning trials (Paper 3), gibberellic acid (GA_3) and gibberellin A4+7 (GA_{4+7}) were applied at different rates during pit hardening to see the effect of these applications on the time required for hand thinning the subsequent season. When the GA_3 and GA_{4+7} were applied at pit hardening, there was no effect on the yield efficiency in the current season. Harvest maturity was only delayed in the case of 'African Delight' with no effect on the fruit size after the GA applications. The fruit firmness was increased, with the GA_{4+7} having a greater effect than the GA_3 applications with no other effects on the fruit quality. At bloom the following season there was a decrease in the flower density in 'Laetitia', 'Larry Ann', 'Pioneer' and 'African Rose' with the GA_3 applications reducing the flower density more than the GA_{4+7} applications. A decrease in flower density would imply a decrease in time to thin trees, but as the percentage of fruit set was not affected, the fruit that needed to be removed by hand was not decreased. In the case of 'Larry Ann' a reduction in the time required to thin was achieved, but the GA_3 and GA_{4+7} applications had similar effects on the reduction in the time required to thin. Following the reduction in the time required to thin, it would have been expected that the yield efficiency could have been decreased. This was not the case as the yield efficiency, along with the fruit size, was not affected. The increase in fruit firmness was again found with the GA_{4+7} again having a bigger effect compared to the GA_3. With spraying performed on the 'Laetitia' and 'Larry Ann' in consecutive seasons no effect was found on the time required to thin.

The efficacy of GA to reduce hand thinning time was erratic and not consistent for all four cultivars. The use of GA as an “indirect” chemical thinner (applied at pit hardening to reduce return bloom) is therefore not recommended for stone fruit. As for other chemical thinning products, the effect of the GA seems to be dependent on the weather, flower dynamics of the tree and tree age. For future studies on GA as a chemical thinner it could be interesting to apply the GA at different dates during pit hardening (flower induction period) and correlate it better to the flower initiation stage to establish the perfect time of application to influence the return bloom. It, however, will always be a risky practice as thinning is completed before the onset of the new season without knowing the conditions during bloom and fruit set and would therefore only be feasible for very heavy setting cultivars like African Rose. The increase in fruit quality through an increase in fruit firmness during the season of GA application could have a positive effect on the storage potential of fruit and could be of benefit.