Chemical thinning of European pear cultivars (*Pyrus communis* L.)

by

Tinashe Gabriel Chabikwa

Thesis presented in partial fulfilment for the degree Master of Science in Agricultural Science (Horticultural Science)

at Stellenbosch University

Supervisor: Prof. Karen I. Theron
Department of Horticultural Science
Faculty of AgriSciences

December 2008

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 owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

22 / 10 / 2008
Date

SUMMARY

Chemical thinning of fruit trees has become a central management practice for ensuring high fruit quality at harvest and return bloom the following season. Three trials were conducted in the 2004/5, 2006/7 and 2007/8 seasons to investigate the efficacy and mode of action of chemical thinning agents on European pear cultivars (*Pyrus communis* L) in the Western Cape, South Africa.

The first trial was conducted in the 2004/5 and 2006/7 seasons to evaluate the efficacy of 50, 100 and 150 mg.l^{-1} 6-benzyladenine (BA), and 30 and 40 mg.l^{-1} naphthylacetamide (NAD) on 'Early Bon Chrétien' pear. BA was more effective than NAD in reducing crop load and improving fruit size. Crop load decreased and fruit size increased with increasing rate of BA. BA significantly improved, whilst NAD failed to improve return bloom.

In the second trial, three experiments were conducted in the 2006/7 and 2007/8 seasons to evaluate the efficacy of 100 to 200 mg.l^{-1} BA on 'Forelle' pear. The first experiment was conducted in the 2006/7 season where BA rates of 100, 125 and 150 mg.l^{-1} generally failed to reduce crop load or to improve fruit size and fruit size distribution and return bloom. The second experiment was conducted in the 2007/8 season where two BA rates, 150 and 200 mg.l^{-1} and a split-application of 3 x 50 mg.l^{-1} improved fruit size. The 200 mg.l^{-1} rate was the most effective treatment. BA did not improve fruit size distribution and return bloom. The third experiment was conducted in the 2007/8 season where the effect of rate and timing of BA applications was evaluated. Two rates, 150 and 200 mg.l^{-1} were applied 8, 11 and 17 days after full bloom (d.a.f.b.). There was no significant interaction between BA rate and application time. The 200 mg.l^{-1} rate and the 11 d.a.f.b. (i.e. 8 to 10 mm average fruit size) applications were more effective in reducing crop load, and improving fruit size. BA at 150 and 200 mg.l^{-1} and at all application times significantly improved return bloom relative to the control.

From these trials we concluded that BA is a reliable thinner for 'Early Bon Chrétien' at rates of 100 or 150 mg.l^{-1}. On 'Forelle', BA is not a reliable thinner and we recommended further trials with BA in combination with other thinning agents.

In the third trial, three experiments were conducted in the 2007/8 season to investigate the mode of action and effect of BA application time on European pear cultivars. The effect of site of application, bourse shoot growth and fruit size at time of application on the efficacy of BA was evaluated. Results from the experiments on the effect of site of application and bourse shoot growth were inconclusive. In terms of fruit abscission, there was a significant interaction between BA application time and fruitlet size. Early BA applications (8 d.a.f.b.) were significantly more effective in promoting fruit abscission, than later (11 and 17 d.a.f.b.) applications. Smaller fruit (6 to 8 mm) were found to be more susceptible to BA-induced fruit abscission than bigger fruit (8 to 12 mm).

OPSOMMING

CHEMIESE UITDUNNING VAN EUROPESE PEERKULTIVARS (*Pyrus communis* L.)

Chemiese uitdunning is ‘n belangrike bestuurspraktyk om goeie vrugkwaliteit te lewer en goeie opvolgblom in die daaropvolgende seisoen te verseker. Tydens hierdie studie is die effektiwiteit en meganisme van werking van na-blom chemiese uitdunmiddels op Europese peerkultivars (*Pyrus communis* L.) ondersoek. Proewe is oor drie seisoene in die Wes-Kaap, Suid-Afrika uitgevoer.

Die eerste proef is in 2004/5 en 2006/7 uitgevoer om die effektiwiteit van 50, 100 en 150 $mg.l^{-1}$ 6-bensieladenien (BA) en 30 en 40 $mg.l^{-1}$ naftaleenasetamied (NAD) op ‘Early Bon Chrétien’ te bepaal. BA was meer effektief as NAD om oeslading te verlaag en die vruggrootte te verbeter. Oeslading het afgeneem en vruggrootte toegeneem met ’n toename in BA konsentrasie. In teenstelling met NAD het BA blom in die daaropvolgende seisoen verbeter.

In die tweede proef is drie eksperimente uitgevoer in die 2006/7 en 2007/8 seisoene om die effektiwiteit van 100 tot 200 $mg.l^{-1}$ BA op ‘Forelle’ pere te ondersoek. In die eerste eksperiment in 2006/7 het 100, 125 en 150 $mg.l^{-1}$ BA gefaal om oeslading te verminder en om vruggrootte, vruggrootte verspreiding en opvolg blom te verbeter. In die tweede eksperiment in 2007/8 het 150 en 200 $mg.l^{-1}$ BA sowel as ’n split-toekenning van 3 x 50 $mg.l^{-1}$ BA vruggrootte verbeter. Die 200 $mg.l^{-1}$ BA behandeling was die mees effektiewe behandeling. BA het nie vruggrootteverspreiding en opvolg blom verbeter nie. Tydens die derde eksperiment in 2007/8 is BA konsentrasie sowel as die tyd van toediening geevalueer. Twee BA konsentrasies, 150 en 200 $mg.l^{-1}$ is 8, 11 of 17 dae na volblom (d.n.v.b.) toegedien. Geen betekenisvolle interaksie het tussen BA konsentrasie en tyd van toediening voorgekom nie. BA teen 200 $mg.l^{-1}$ en die 11 d.n.v.b toediening (8 tot 10 mm gemiddelde vruggrootte) was die meer effektief om vruglading te verminder, en vruggrootte te verbeter. BA het opvolg blom betekenisvol verbeter in vergelyking met die kontrole.

Uit hierdie proewe kon afgelei word dat BA redelik betroubaar werk as uitdunmiddel vir ‘Early Bon Chrétien’ pere teen 100 of 150 $mg.l^{-1}$. Op ‘Forelle’ pere was BA nie so ’n

effektiewe uitdunmiddel nie en verder proewe met BA in kombinasie met ander uitdunmiddels word aanbeveel.

In die derde proef is drie eksperimente in die 2007/8 seisoen uitgevoer om die meganisme van werking en die effek van tyd van BA toediening op Europese peerkultivars te ondersoek. Die effek van toedieningsposisie, beurslootgroei en vruggrootte tydens tyd van toediening is geevalueer. Resultate uit die eksperimente oor toedienings en beurslootgroeiis onbeslis. In terme van vrugafsnoering was daar ’n interaksie tussen tyd van aanwending en vruggrootte. Vroeë BA toedienings (8 d.n.v.b.) was betekenisvol meer effektief om vrugafsnoering te stimuleer as later (11 en 17 d.n.v.b.) toedienings. Kleiner vruggies (6 tot 8 mm) was meer vatbaar vir BA-geïnduseerde afspening as groter vrugte (8 tot 12 mm).

ACKNOWLEDGEMENTS

I would like to thank the following people and institutions:

Prof. K. I. Theron my supervisor, my fieldwork and the subsequent study would have been less exciting, more difficult and probably unattainable if it were not for her efforts. I am deeply grateful for all her patience, time, constructive criticism, encouragement and assistance with data analysis;

Mr. G. Lötze for support and guidance in planning and implementing the project;

The lecturers and staff of the Department of Horticultural Science, Stellenbosch University for their assistance, advice and encouragement throughout my study;

The technical assistants, in particular Mr G.H. Groenewald;

Mr Anthony and Nicholas Dicey of La Plaisante Estate;

Philip Dicey of Buchuland Farm;

The manager and staff of Oak Valley Estates Elgin;

My fellow students and friends for their encouragement;

Professors Uniedt and Blanke (2001) for permission to reproduce copyright material;

The Department of Horticultural Science, Stellenbosch University for their generous financial support.

TABLE OF CONTENTS

GENERAL INTRODUCTION

Under optimum conditions, fruit trees will produce an excessive amount of flowers to cater for potential flower and fruit loss due to adverse weather conditions such as late spring frosts and drought. According to Williams (1994), only 5 to 10 % of flowers on fruit trees with heavy blossom densities, are needed to set a full crop. Under conditions favourable for fruit set, these trees will set more fruits than they can support, which in turn leads to a reduction in fruit size and quality at harvest. Excessive cropping can also inhibit flower bud formation and so reduce flowering the following season, leading to an undesirable alternate bearing pattern. Fruit trees have a self-regulatory mechanism that enables them to shed excess flowers and/or fruits early in the season, the so-called "June drop" (Roberts *et al.,* 2002; Webster, 2002). However, from a horticultural point of view, this self-regulatory mechanism is not sufficient to guarantee fruits of commercially acceptable quality (Dal Cin *et al.,* 2005). The economic disadvantages of excess crop load have resulted in considerable research on fruit thinning and widespread commercial application of this practice (Stover, 1999).

Fruit thinning is the removal of a portion (excess) of the crop before it matures on the tree. Hand thinning is the conventional method used to reduce crop load, however, high costs and unavailability of labour, have led growers and researchers to seek alternative methods of reducing/regulating crop loads. Alternative methods that have been evaluated are the use of machinery (mechanical thinning) and the use of chemicals (chemical thinning). Whilst mechanical fruit thinning has proved to be useful on stone fruits (Dennis, 2000), it lacks precision and often leads to over-thinning and poor fruit distribution within the canopy (Westwood, 1993). It is indiscriminate and injures fruit (especially when applied on pome fruit), tree limbs and buds (Menzies, 1980; Wertheim, 2000).

Chemical thinning is widely perceived as the best alternative to hand thinning. It can be implemented at bloom (blossom thinning) and/or post-bloom (fruitlet thinning). The use of chemicals to reduce crop load has been evaluated for over 50 years and has yielded promising results in some fruit species (Dennis, 2000; Wertheim, 2000; Webster 2002). Within the pome fruit group, most research on chemical thinning has been done on apples and relatively little on pears, therefore there is very limited understanding of the efficacy of chemical thinning agents on pears (Williams, 1994; Wertheim, 2000; Webster, 2002).

The hormonal post-bloom chemical thinning agents, 6-benzyladenine (BA) and naphthylacetamide (NAD) have yielded the most promising results in fairly recent evaluations on European pear cultivars (Wertheim, 2000; Webster, 2002; Wertheim and Webster, 2005). The aim of this study was (i) to review the relevant literature on the topic, (ii) to evaluate the efficacy of the thinning agents, BA and NAD on 'Early Bon Chrétien' pear, (iii) to evaluate the efficacy of BA on 'Forelle' pear and (iv) to investigate the mode of action of BA on pears.

References

Dal Cin, V., Danesin, M., Ramina, A., Dorigoni, A., Boschetti, A. and Ruperti, B. 2005. Fruit abscission as related to fruit quality. *Acta Hort*. 682: 781 - 788.

Dennis, F.G. 2000. The history of fruit thinning. *Plant Growth Regul.* 31: 1 - 16.

Menzies, A.R. 1980. Timing, selectivity and varietal response to mechanical thinning of apples and pears. *J. Hort. Sci*. 55: 127 - 131.

Roberts, J.A., Elliot, K.A. and Gonzales-Carranza, Z.H. 2002. Abscission, dehiscence and other cell separation processes. *Annu. Rev. Plant Biol*. 53: 131 - 158.

Stover, E.W. 1999. Relationship between intensity of flowering and cropping in fruit and nuts (abstract). *HortScience* 34: 561.

Webster, A.D. 2002. Current approved thinning strategies for apples and pears in recent thinning research in Europe. *Compact Fruit Tree* 35: 73 - 76.

Wertheim, S.J. 2000. Developments in the chemical thinning of apple and pear. *Plant Growth Regul.* 31: 85 - 100.

Wertheim, S.J. and Webster, A.D. 2005. Manipulation of growth and development by plant bioregulators. pp. 267 - 288. In: Tromp, J., Webster, A.D. and Wertheim, S.J. (Eds.), Fundamentals of temperate zone fruit production. Leiden. Backhuys.

Westwood, M.N. 1993. Temperate-zone pomology: physiology and culture. (3rd Ed.). pp. 210 - 215. Timber Press. Oregon.

Williams, M.W. 1994. Factors influencing chemical thinning and update on new chemical thinning agents. *Compact Fruit Tree* 27: 115 - 122.

CHAPTER 1. LITERATURE REVIEW: - CHEMICAL THINNING OF EUROPEAN PEAR CULTIVARS

1. Introduction

Effective crop load management is often critical to viable fruit production, having a profound impact on fruit size and quality at harvest, regular cropping and farm labour costs. An excessive crop load usually results in a relatively higher percentage small fruits as compared to large fruits (Lötze and Bergh, 2004). This is often due to insufficient leaf area per fruit to ensure adequate fruit development. According to Gianfagna (1987), fruit size declines as leaf: fruit ratio is reduced to/below 30:1. The effect of heavy crop loads on fruit size distribution at harvest varies between fruit species and cultivars. Some pear cultivars are generous bearers, often prone to overbear and it is a common sight to see the branches of such trees propped up to prevent them from breaking under the weight of the fruit (Davis, 1928). It is therefore, often necessary to reduce crop loads (fruit thinning) to ensure that the remaining fruits attain sizes that are of high commercial value. A heavy crop load in one year is often reflected in a strong reduction of flower formation and fruit yield for the following season, resulting in alternate "on" and "off" years with respect to bloom and crop load (Jonkers, 1979; Greene, 2000; Tromp, 2000). Early fruit thinning can therefore reduce alternate bearing, as flower bud initiation and formation in pear fruit trees occurs in the preceding year, about 60 days after full bloom (d.a.f.b.) (Westwood, 1993; Tromp, 2000; Reynolds *et al.,* 2004).

This literature review section will cover the research problem, possible solutions and research completed on chemical thinning of European pears (*Pyrus communis* L.*).*

2. Motivation for thinning fruit trees

Commercial fruit growers seek to increase profitability by improving yield levels, fruit size and quality whilst minimising production costs. Chemical and/or physical manipulations of fruit trees are required to improve fruit size, yield and quality (Looney, 1983). However, these manipulations are often costly and thus need to be justified. For example, discriminative fruit thinning improves pack-house efficiency, thus reducing handling costs as malformed, diseased, sun burnt and insect scarred fruits are removed in the orchard. In this section, the benefits of thinning fruit trees will be discussed.

2.1 Effects of thinning on fruit quality

Fruits with reduced external and internal quality at harvest, often perform poorly post-harvest (Williams, 1994). Only fruit well supplied with carbohydrates attain good flavour and colour (Link, 2000). Adequate carbohydrate supply to developing fruit is often compromised on trees with excessive crop loads, i.e. three or more fruit per cluster, depending on cultivar. Therefore, reducing fruit set as early as possible to one or two fruits per cluster (Kadam *et al.,* 1995; Theron *et al.,* 2002) is often recommended, in order to reduce competition between fruit for assimilates and minerals. This will improve external and internal fruit quality parameters such as fruit size, colour, total soluble solids and titratable acid (Link, 2000).

Fruit size is a major criterion of fruit quality. As fruit production and international trade increases, customers are demanding a better fruit quality consequently, prices of small to medium-sized fruit are either remaining constant or declining (Dennis, 2000). Fruit weight and diameter are the main indicators of fruit size. Average fruit weight is negatively correlated with crop load (Link, 2000). Since fruit size distribution per tree corresponds to a normal distribution curve, every effective thinning treatment shifts the curve from the lower size categories to the higher ones (Link, 2000). However, if overdone, thinning programs may result in large fruit which may be of a lower commercial value (Williams, 1994; Wertheim, 2000; Webster, 2002a). Larger fruits do not always give the highest returns on the market. In some cases, 'Conference' pear growers are not keen to implement thinning strategies because higher prices may be obtained with smaller fruit sizes and substantial price reductions may occur in size classes larger than 55 mm diameter (Wertheim, 2000). According to Nicotra (1982), large pear fruit are more susceptible to soft-rot.

Apart from potentially improving fruit size, fruit thinning can affect other aspects of fruit quality. High fruit cluster densities often result in blemished fruit with rub marks, bruising and malformation. Fruit thinning can induce, increase or reduce russet, depending on the fruit specie, cultivar and method of thinning used. Russet can be defined as a periderm that replaces the epidermis, usually as a result of injury. It forms a continuous layer of protective tissue (Jackson, 2003), which greatly reduces fruit cosmetic quality. Chemical thinning is performed during the most sensitive phase of fruit development for the induction of russet and it is therefore expected that thinning agents might influence fruit russet (Link, 2000). Chemical thinning agents can promote or reduce russet, depending on the type and rate of the

thinning agent used, as well as the time of application. The classical thinning compounds naphthaleneacetic acid (NAA) and its amide (NAD) often show a smoothing effect on the skin (epidermis) of the fruit (Link, 2000), thus reducing the incidence of russet. On the other hand, carbaryl and ammonium thiosulphate (ATS) may increase fruit russet to unacceptable levels when applied during the early stages of fruit development, but less when applied later (Williams, 1994; Link, 2000; Wertheim, 2000).

Fruit thinning increases the extent and intensity of surface colour in red fruit cultivars (Link, 2000), as the ratio of leaves to fruit has a marked effect on red colour development (Jackson, 2003). The red colour of blushed fruit, such as 'Forelle' pear, is due to the presence of anthocyanin pigments in the hypodermal layers of the skin (Dussi *et al*., 1995). High light levels and relatively low temperatures stimulate anthocyanin synthesis (Theron *et al.,* 2002; Wand *et al.,* 2005). Anthocyanin concentrations decrease rapidly in the absence of light, indicating that continued light is required for synthesis to make up for dilution and turnover of anthocyanin (Steyn *et al.,* 2005). The colour intensity (absorbance) of anthocyanins increases in the presence of the carbohydrates, glucose, maltose and sucrose (Lewis *et al.,* 1995; Steyn *et al.,* 2002). High fruit densities often result in poor light distribution within the cluster and low assimilate import per fruit. Fruit thinning may therefore result in better light distribution and higher nutrient import by the remaining fruit, thus improving colour development in fully-coloured and blushed cultivars.

2.2 Effects of thinning on alternate bearing

Alternate bearing is an undesirable trait that is common in most deciduous fruit trees (Dennis and Hull, 2003). Cultivars with a high proportion of short fruiting shoots (spur type) usually have a strong alternate bearing tendency, whereas cultivars with longer shoots (tip-bearing type) are able to flower annually (Davenport, 2000). Therefore, alternate bearing is likely to be severe with most pear cultivars as pear flower buds are formed almost exclusively on spurs (Tromp, 2000). However, according to Westwood (1993), most pear cultivars are not alternate bearers and tend to flower annually. A high bloom density and subsequently, heavy fruit set in one year is often reflected in a strong reduction in blossom density the following season resulting in an alternation of "on" and "off " years with respect to crop load (Jonkers, 1979; Davenport, 2000; Greene, 2000; Tromp, 2000).

The year with heavy cropping results in small fruit and the subsequent year with a small crop results in large fruit, both situations being undesirable (Bergh, 1985; Greene, 1999; Bertelsen, 2002b). The quality of fruit in an "on-year" is usually inferior to the quality of a regular bearing cultivar (Jonkers, 1979). Trees which were previously heavily cropped often have smaller flowers, a shorter effective pollination period (EPP) and lower initial fruit set compared to previously thinned trees (Bergh, 1985; Buszard and Schwabe, 1995; Bertelsen, 2002b). Fruit from heavily cropped trees were found to have a lower number of cells in the cortex, compared to thinned trees. The differences in cell number were already significant when flowers where in an early developmental stage (Bergh, 1985). The presence of fruit is antagonistic to flower induction ultimately leading to alternate bearing, due to:

- hormonal factors controlled by the seeds (Stover, 2000; Tromp, 2000),
- competition between the fruitlets and the developing flower buds for assimilates and other compounds that promote flowering (Westwood, 1993; Tromp, 2000).

Gibberellins (GAs) can suppress flower initiation or cause early floral abortion in most pome and stone fruit trees, if present in supra-optimal quantities during the critical stages of flower development (Griggs *et al.,* 1970; Huet, 1973; Weinbaum *et al.,* 2001). It is widely believed that GAs inhibit flower bud formation by lengthening the plastochron (Faust, 1989; Pharis and King, 1985; Moran and Southwick, 2000). A plastochron is the interval between the initiation of successive leaf primordia. A critical number of nodes have to be initiated within the bud, typically 16-20, for floral induction to occur. If the plastochron is lengthened to more than 7 days in the case of apple, the critical number of nodes may not be attained, so the bud remains vegetative (Faust, 1989; Moran and Southwick, 2000; Tromp, 2000).

However, there is little evidence that GAs are transported into potential flower buds (Bangerth, 2005; 2006). An increase in the amount of IAA exported from seeded fruits was observed during the critical phase of flower induction while seedless fruits, which reportedly do not inhibit flower induction, had a much lower polar IAA export (Bangerth, 2005). This led to the suggestion that GAs inhibit flower bud formation indirectly, by stimulating IAA export out of fruitlets and shoot tips. In this case, GAs act as the primary messenger stimulating the second messenger IAA (Bangerth, 2006). The polar IAA transport pathway would then act as the transported message, transferring the inhibiting seed/shoot tip signal into the meristem (Callejas and Bangerth, 1998, Bangerth, 2006). IAA transport correlatively

inhibits flower induction. Therefore, during critical stages of flower bud formation, GAs and polar auxin transport play a role as inhibiting signals (Bangerth, 2006).

Flower bud formation in pear fruit trees is a process of long duration, the greater part taking place in the preceding season (Davenport, 2000; Stover, 2000; Tromp, 2000; 2005). Excessive GAs produced by seeds are believed to play a significant role in triggering alternate bearing in many fruit tree species (Gil *et al.,* 1972; 1973; Stover, 2000; Tromp, 2000). On 'Bon Chrétien' pear trees, a heavy crop of seedless fruits was followed by heavy flowering the following season, whereas, flowering was inhibited by an equivalent crop of seeded fruits (Huet, 1973). Weekly de-fruiting trials on 'Bon Chrétien' pear trees showed that the inhibitory effect may manifest itself 4 - 6 weeks after bloom, when the fruits were 15 mm in diameter, peaking 9 weeks after bloom, which coincides with the time of flower induction (Huet, 1973; Westwood, 1993; Tromp, 2000).

However, the inhibitory effect of seed-produced GA's may be an oversimplification, as the early removal of fruits may stimulate shoot growth. Since young leaves and shoot tips are rich sources of GAs, shoot growth during the critical stages of flower bud formation may have an inhibitory effect (Tromp, 2000; Bangerth, 2005; Tromp, 2005). The role of seeds in the inhibition of flower-bud formation on pear trees is controversial. When Griggs *et al.* (1970) compared the effects of seeded and seedless fruit on return bloom, the results were inconclusive, for neither consistently inhibited flowering. In addition to this, seedless fruit can also inhibit return bloom (Weinbaum *et al.,* 2001).

Although our understanding of the consequences of thinning for return bloom and alternate bearing is still very incomplete (Tromp, 2000), it is generally accepted that early thinning is a major strategy in preventing alternate bearing (Bound and Jones, 2004; Bertelsen, 2002a). According to Williams (1981), the key to preventing alternate bearing is to start some sort of chemical thinning as soon as the trees have more than 50 % of the growing points flowering. Lombard (1982) suggested that 90 % of the flowers or fruits on pear trees with heavy blossom densities need to be removed within 6 weeks of anthesis in order to consistently crop pear trees annually. It must also be noted that thinning agents may affect flower bud formation directly without any intervention of fruits (Tromp, 2000).

2.3 Effects of thinning on tree vigour

Heavy crop loads often result in limb and branch breakage (Davis, 1928; Wertheim, 1997). This is undesirable as reserves in the storage tissues of these branches are lost, potential bearing area is lost and the resultant wound(s) provide a convenient passage of entrance to numerous pathogens. Because of high competition for assimilates, fruit ripening is delayed on heavily cropped relative to lightly cropped trees. This would lead to the exhaustion of the tree's reserves and reduced cold hardiness, thus reducing vigour (Jonkers, 1979; Byers *et al.,* 2003). According to Marsal *et al.* (2008), fruit thinning may enhance tree vigour by improving tree water status during drought. This is because excessive crop loads inhibit root development, as fruits compete with roots for assimilates (Wertheim *et al.,* 2001). The fruits will first deplete reserves and then withhold assimilates from root growth (Wolstenholme, 1990). Therefore, eliminating some fruit sinks on pear trees, increases the availability of assimilates which would enhance root growth, thus allowing greater exploitation of soil water (Marsal *et al.,* 2008). However, according to Naor (2001), thinning pear trees does not always improve tree water status. Fruit thinning, therefore helps maintain tree vigour by reducing demand for assimilates, mineral salts and water, rendering the tree more resistant to drought, frost, diseases and nematodes.

2.4. Conclusion on motivation for thinning fruit trees

Due to high levels of competition in the export market, bigger fruit generally obtain better prices in the first world markets. The minimum size requirements for the USA is particularly severe (Lötze and Bergh, 2004; Turner *et al.,* 2005). Fruit thinning is therefore an essential management practice as it enables optimum crop loading which enables the remaining fruit to reach marketable sizes at harvest. However, besides fruit thinning, other cultural factors such as dwarfing rootstocks, balanced fertilizer programs and appropriate pruning practices are important to achieve adequate pear size (Meland, 1998). Fruit thinning promotes regular cropping and maintains tree vigour as additional benefits. However, fruit thinning is to be managed carefully and in such a way, that the grower will not sacrifice income when the price of large fruit does not warrant the lower tonnage (Wertheim, 2000; Lötze and Bergh, 2004). Stover *et al.* (2001) formulated a method for assessing the relationship between crop load and crop value following fruit thinning.

3. Methods of thinning fruit trees

Selecting an appropriate method of thinning fruit trees is of paramount importance and is influenced by species and cultivar. The overall objective of fruit thinning is to reduce crop load as early as possible, thereby enhancing fruit size and improving return bloom. Early thinning reduces the potential wastage of assimilates by fruitlets that are to be discarded, exposing meristems to high gibberellic acid (GA_3) levels. There are three principle methods of thinning fruit trees, these are hand, mechanical and chemical thinning.

3.1 Hand thinning

Despite the advances made over the past 75 years, hand thinning remains an important tool for fruit growers (Dennis, 2000). Hand thinning when fruitlets are 10 mm in diameter, that is, 14 to 21 days after full bloom (d.a.f.b.), can prove most effective in optimising levels of fruit set (Bergh, 1985; Meland, 1998; Webster 2002b). Hand thinning has the advantage of being a low risk strategy, it can be implemented after the risk of frost damage (due to late spring frosts) has elapsed and facilitates precise optimum crop loading and fruit distribution within the canopy (Webster 2002a). Hand thinning is an environmentally acceptable method of reducing crop load. It is discriminative, thus malformed, blemished fruit and weak blossoms are removed rather than healthy ones, thus reducing handling costs. Hand thinning can be justified economically, as the increase in percentage higher grade fruit could also result in higher prices (Wells *et al.,* 1998). According to Wells *et al.* (1998) thinning of 'd'Anjou' pears by hand in Oregon, USA, to three fruitlets per cluster is feasible as it would return up to US$1600 more per hectare than the unthinned control.

However, hand thinning is a labour intensive practice and when applied with the degree of detail and concentration required to do a good job, it can account for as much as 20 % of the total costs of production (Jackson and Looney, 1999). On a commercial scale, hand thinning requires much labour to achieve the required thinning effect within the optimum time span, which is 14 to 21 d.a.f.b. (Knight, 1986; Meland, 1998; Webster, 2002a). Unavailability of labour and rising labour costs have become major constraints for fruit growers around the world and has led to research into alternative methods of thinning fruit trees, viz., mechanical and chemical thinning (Williams, 1994; Webster, 2002a).

3.2 Mechanical thinning

The reduction of fruit and flower numbers using mechanical aids has been evaluated on fruit trees. This method of thinning is more appropriate with stone fruit, during the pit hardening stage, prior to final swell (Dennis, 2000). Prototype machines have been developed which remove flowers or fruitlets using flails or combing devices (Webster, 2002a). The use of power tree shakers of the type used to mechanically harvest fruit has been evaluated. The shaker head is attached to the base of the tree trunk and energy is applied under careful control by the operator (Westwood, 1993; Rosa *et al.,* 2008). Other apparatus used to mechanically thin fruit trees include rope thinners, clubs, hot air blowers and the use of water at high pressure (Webster, 2002a). When using rope thinners, long ropes are attached to an over-tree boom and are dragged through the trees, to knock off blossoms and/or fruitlets (Dennis, 2000). The use of hot air blowers to reduce the number of blossoms and the use of high pressure spray guns which spray water at very high pressures (> 3 MPa) to reduce the number of blossoms/ fruitlets have been evaluated on apple and plum trees (Webster, 2002a).

The reduction of fruit or blossom numbers using mechanical methods is very difficult to execute without causing unwanted damage to fruits and foliage (Webster, 1993). The use of these prototype machines often results in marked and bruised fruit which are of low market value. The use of power tree shakers may harm the tree and also lacks precision as it requires a high level of skill to prevent over thinning (Westwood, 1993). The major problem with power tree shakers, which still remains unsolved, is removal of larger fruit due to larger inertial forces (Rosa *et al.,* 2008). The use of rope thinners and hot air blowers may damage leaves and woody tissue (Webster, 2002a). Unlike hand thinning, mechanical methods of thinning fruit trees are indiscriminate, thus, healthy blossoms and fruitlets may be removed instead of the weaker ones. Mechanical thinning is not recommended for most fruit species, particularly pome fruits (apples and pears), because they are easily bruised and the damage is visible on mature fruit (Dennis, 2000). As a result, none of the machines used in mechanical thinning have achieved any widespread commercial acceptance (Webster, 2002a).

Mechanical thinning of fruit and/or blossoms is therefore not a viable alternative to hand thinning as it is not applicable to most fruit species including the European pear (*Pyrus communis* L.).

3.3 Chemical thinning

The use of chemicals to reduce fruit and flower numbers in commercial orchards is widely practised. It can be implemented at bloom (blossom thinning) and/or post-bloom (post-bloom thinning). In blossom thinning programs, chemicals are used to reduce potentially excessive crop loads on trees by preventing fruit set on a proportion of flowers. In post-bloom thinning programs, chemicals are used to reduce crop loads by magnifying/ amplifying natural fruitlet drop expressed at the moment of application (Wertheim, 2000; Bangerth, 2004). Given the natural fruit drop dynamics, the maximum thinning effect is often exhibited when the chemical is applied at the beginning of natural fruit drop ("June drop") (Dal Cin *et al.,* 2005), however this depends on fruit species and actual chemical used.

Although it has been practised for over 60 years (Dennis, 2000), chemical thinning is still partially unreliable (Wertheim, 2000). Variability in outcome is a major drawback (Wertheim, 1997), due to the large number of variables (principally weather and tree conditions) over which the grower has little or no control. The success of chemical thinning is dependant on the absorption of the growth regulator into the tree through the foliage and fruits (Lombard, 1967; Greene and Bukovac, 1972; Schönherr *et al.,* 2000). Surfactants can be added to the growth regulator to enhance its absorption (Greene and Bukovac, 1974). Environmental conditions before and after application as well as tree conditions, are important co-determinants of thinning efficacy (Stover and Greene, 2005). Temperature, humidity and light intensity are the principle environmental factors affecting absorption of the chemicals into the tree through leaves and fruit (Williams, 1979).

Precautions have to be taken to prevent fruit marking, russet and leaf burning (mainly primary spur leaves), particularly with the application of blossom thinners (Bound and Mitchell, 2002a; Fallahi and Willemsen 2002; Webster, 2002a; b). These primary leaves are particularly important in sustaining early cell division of the developing fruits and ensuring calcium uptake by these fruits (Taiz and Zeiger, 2002). It must be noted that supplementary hand thinning is often required after chemical thinning, to break up clusters of fruit following chemically-induced fruit abscission (Williams, 1973; Wertheim, 1997; Dennis, 2000). The next section deals specifically with the chemical strategies for thinning European pear cultivars (*Pyrus communis* L.).

4. Chemical thinning of European pears *(Pyrus communis L.)*

The use of chemicals to thin European pears has become a standard orchard practice in most fruit growing countries, as a method of getting consistently high yields of high quality fruits and reducing alternate bearing of trees. However, it is not as widely used as in the case of apple production, because pear flowers are more prone to frost damage and insufficient pollination and fruit set. Also, several of the popular pear cultivars are not very fertile (Looney, 1983; Bonghi *et al.,* 2002; Bertelsen, 2002a). The problem of excessive fruit set and reduced fruit size at harvest is particularly severe with varieties which are intrinsically smaller than the average fruit size (Webster, 2002a), as well as 'early' cultivars. Trees on which fruits are harvested early, in contrast to late, have been shown to have higher bloom densities and heavier fruit set the next spring (Tukey, 1981), due to the effect of early harvesting on tree reserves, flower bud development and flower quality. Three chemical strategies can be implemented to reduce excessive fruit set. These are, (i) inhibition of flower induction, (ii) blossom thinning and (iii) post-bloom thinning (Moran and Southwick, 2000; Webster, 2002a; b).

4.1 Inhibition of flower induction

It has been known for over 75 years that gibberellins (GAs) inhibit the initiation of reproductive buds when applied during the growing season, thereby reducing the density of flower buds for the following season (Lombard, 1967; Moran and Southwick, 2000; Webster, 2002a). GA_3 inhibits normal bloom of pear when applied prior to floral induction, but is ineffective afterwards (Knight and Browning, 1986; Tromp, 2005). The efficacy of GAs in reducing return bloom varies with cultivar, rate used and application time. When applied on 'Bon Chrétien' pear trees at the phenological stages of bud swell, pink bud, full bloom and petal fall, 200 to 500 $mg.l^{-1}$ GA_3 reduced return bloom (Griggs and Iwakiri, 1961). Full bloom and petal fall applications of 50 $mg.l^{-1}$ GA_3 completely inhibited return bloom on 'Conference' pear trees (Turner, 1973), while full bloom applications of 10 to 30 $mg.l^{-1}$ GA_3 reduced return bloom on 'Flemish Beauty' pear trees (Negi and Sharma, 2005). GA_3 at 5 to 25 $mg.l^{-1}$ applied 30 days after full bloom (d.a.f.b.) reduced return bloom on 'Seckel' pear trees (Lombard and Strang, 1978). Climatic conditions may also affect the ability of GAs to inhibit return bloom. GA_3 at 20 to 100 $mg.l^{-1}$ reduced return bloom on 'Bon Chrétien' pear

trees in New York (Dennis *et al.,* 1970), but was ineffective in California (Moran and Southwick, 2000).

However, this strategy is difficult to use with precision as it is difficult to control the degree of flower bud inhibition achieved as Coetzee and Theron (1999) found in nectarine. It may have deleterious effects on the growth and winter hardiness of the trees, as well as reducing the quality of the reduced numbers of flowers formed (Webster, 2002b). If reproductive bud quality is reduced, fruit set in the subsequent season may also be reduced (Bergh, 1985; Bertelsen, 2002a). Most growers usually prefer to have more flowers than strictly necessary to set a full crop in order to compensate for losses caused by adverse weather conditions such as spring frosts (Wertheim, 2000; Webster, 2002b). The inhibition of flower induction is therefore currently not a viable strategy of reducing excessive fruit set on European pear trees.

Blossom and post-bloom thinning are more popular thinning strategies (Wertheim and Webster, 2005). However, some of the chemicals that are used for thinning fruit trees have been de-registered in several fruit growing countries due to their negative effects on the environment, as well as high re-registration costs (Williams, 1994; Webster, 2002a; Dennis and Hull, 2003). Chemicals that are already approved for use on a major crop (such as foliar fertilizers) and substances occurring in plants naturally (hormones) which have thinning abilities are the only commercially available thinning agents in Europe (Webster, 1993). At present, carbaryl is still a registered chemical thinner of apples in South Africa.

4.2 Blossom thinning

This is the removal of a proportion of flowers at bloom or prevention of fruit set of a proportion of flowers with chemical sprays (Moran and Southwick, 2000; Webster, 2002a). Blossom thinning is particularly important for cultivars that annually set abundantly and for all cultivars in orchards situated in climatic zones suitable for fruit set (Kadam *et al.,* 1995; Wertheim and Webster, 2005). Blossom thinning agents are becoming more acceptable in drier regions where the risk of frost during the bloom period is low (Williams, 1994; Moran and Southwick, 2000). Blossom thinning has advantages over post-bloom thinning in that the earlier thinning is performed, the greater the potential effect on fruit size and return bloom (Bergh, 1985; Moran and Southwick, 2000; Dennis and Hull, 2003). To be commercially

acceptable, a blossom thinning agent should reduce fruit set on full bloom trees by 25 to 50 %. This is usually sufficient for return bloom and annual cropping as only 5 to 10 % of blossoms on fruit trees with heavy blossom densities, are needed to set a full crop (Williams, 1994).

Blossom thinning agents prevent pollen germination and growth on the stigma and/or stimulate degeneration of the female gametes (ovules) in the ovaries (Williams, 1994; Wertheim 2000; Webster, 2002a). They are also believed to desiccate vital female organs (stigma, style or ovary) of flowers, thus preventing fertilisation (Moran, and Southwick, 2000; Fallahi and Willemsen 2002). Temperature, humidity, rate, cultivar and the percentage of flowers open at spraying time are important factors determining the efficacy of blossom thinning agents (Moran and Southwick, 2000; Fallahi and Willemsen, 2002; Bound and Jones, 2004). Blossom thinning agents are more effective at higher rates, temperatures and relative humidity (Wertheim, 2000; Bertelsen, 2002a). Therefore, combinations of extremely high temperature and humidity should be avoided to reduce the chances of excessive thinning and phytotoxicity (Wertheim, 2000).

Blossom thinning is not popular with growers because they are reluctant to eliminate a proportion of flowers prior to ensuring adequate fruit set (Webster, 2002b), especially if the risk of spring frost is high or where higher humidity and longer drying times increase the potential for fruit russet (Bertelsen, 2002a; Fallahi and Willemsen 2002). High rates of blossom desiccants have been found to cause severe scorching of flowers and leaves and meristems (Bertelsen, 2002a). It must be noted that the scorching of leaves may be partly necessary for fruit set reduction, as it increases inter-sink competition. Ammonium thiosulphate, lime sulphur and ethephon have been evaluated as blossom thinning agents for European pear cultivars and will be discussed individually in the following sections.

4.2.1 Ammonium thiosulphate

Ammonium thiosulphate (ATS) is a widely used foliar fertiliser that can also be used to reduce fruit set when applied during the flowering period. ATS was first evaluated as a blossom thinning agent on peach trees in 1984, since then, it has also proven to be an efficient thinner of apples and pears (Bertelsen, 2002a). It is environmentally acceptable, as it does not

leave residues because it breaks down to simple, naturally occurring compounds soon after application (Bound and Mitchell, 2002a). ATS effectively reduced fruit set on 'Conference', 'Winter Cole', 'Clara Frijs' and 'Packham's Triumph' pear trees by desiccating vital female organs (Wertheim, 2000; Bertelsen, 2002a; Bound and Mitchell, 2002a; Bound and Jones, 2004).

ATS is effective on flowers that have reached anthesis at the time of application (Bertelsen, 2002a). To achieve the target crop load, ATS has to be applied when sufficient flowers have been fertilised and set fruit, thus, the later the application the greater the fruit set is likely to be (Fallahi and Willemsen, 2002; Bound and Mitchell, 2002a). This is because blossom desiccants do not thin pollinated blossoms where fruit set has been achieved prior to spray application (Bound and Mitchell, 2002a; Bound and Jones, 2004). Likewise if application is too early, late opening flowers are likely to be unaffected and are likely to set fruit, resulting in a heavy crop load (Bound and Mitchell, 2002a). Thus, timing is a critical factor in the success of ATS and other blossom desiccants.

ATS is effective at temperatures as low as 14 °C and as high as 22 °C (Bertelsen, 2002a). The rate of ATS must be sufficiently high to deactivate the style/ stigma without damaging the receptacle which forms the fruit, or causing unacceptable damage to leaves and buds (Bound and Mitchell, 2002a). According to Fallahi and Willemsen (2002), foliage and bud burning can result from the application of ATS at rates exceeding 2.5 %. It must be noted that even at rates that are not phytotoxic, fruit defects such as russet can be a problem (Williams, 1994). When rates of 1, 2 and 3 % ATS were applied at full bloom on 'Conference', only the 3 % rate reduced fruit set and improved fruit size. However, it caused phytotoxicity and did not promote return bloom (Wertheim, 1997; 2000), possibly due to leaf damage.

When using ATS, leaf damage is increased by high humidity which prolongs drying. Applying a wetting agent can confound the problem (Bertelsen, 2002a). Applying ATS prior to wet and humid periods, causes fruit and foliage injury and produces erratic results. ATS is therefore not recommended in regions where humid conditions prevail during the bloom period (Byers *et al.,* 2003). Rewetting of leaves after ATS application, even if only resulting from heavy dew the next morning, can greatly increase chemical uptake, leaf damage and the thinning response (Dennis, 2000). Apart from being temperature and humidity dependent, the

efficacy and phytotoxicity of ATS is also cultivar dependent. ATS has proven to be an effective blossom thinner of 'Packham's Triumph' pear at rates of 1 and 1.5 % without causing unacceptable phytotoxicity, when applied at 20 % bloom, with a second application at 50 % bloom to enhance the thinning effect (Bound and Mitchell, 2002a). At 80 % bloom, little thinning was achieved, demonstrating the importance of timing of application to reduce fruit set (Bound and Mitchell, 2002a).

Similar results were observed on 'Winter Cole' pear, where application of 1.5 % ATS resulted in near commercial levels of cropping without excessive foliar damage (Bound and Jones, 2004). An ATS rate of 0.3 % was ineffective, while rates of 3 and 4 % caused excessive phytotoxicity (Bound and Jones, 2004). However, unlike with 'Packham's Triumph', full bloom applications reduced fruit set the most, while the 50 % bloom applications were more effective than 20 % bloom applications. ATS also reduced the number of viable seeds in remaining fruit (Bound and Jones, 2004). Fruit weight of 'Winter Cole' was not enhanced after thinning with ATS which was partially attributed to foliar damage (Bound and Jones, 2004). Unlike with 'Winter Cole' and 'Packham's Triumph', damage to spur leaves was observed on 'Clara Frijs' pear at rates as low as 1 to 2 % ATS. Although positive thinning effects were observed, fruit size was not increased and return bloom was greatly reduced (Bertelsen, 2002a). This reduction of return bloom was likely the consequence of severely damaged and dysfunctional spur leaves (Bertelsen, 2002a). This is because, damaging spur leaves between full bloom to 28 d.a.f.b. will inhibit or greatly suppress flower bud formation in the adjacent bourse shoot (Luckwill, 1970).

4.2.2 Lime sulphur

Lime sulphur (LS) is used as a blossom thinning agent in conventional and organic fruit production systems (Garriz *et al.,* 2007; Weibel *et al.,* 2007). Its mode of action is similar to that of ATS (Webster, 2002b). Presently in Europe, with the exception to Switzerland where it is not allowed in organic production, deciduous fruit growers make 2 to 3 applications of 2 to 5 % LS during the bloom period (McFerson *et al.,* 2005; Weibel *et al.,* 2007).

Preliminary results in Europe suggest that LS can achieve some thinning on 'Bon Chrétien' and 'Bosc', but is generally not as effective as ATS (McFerson *et al.,* 2005). On 'Abate

Fetel' pear, 7 % LS applied at 30 % bloom reduced fruit set and increased final fruit weight by 17 %, compared to the unsprayed control, without affecting fruit quality (Garriz *et al.,* 2007). 'Amanlis' and 'Moltke' were thinned with 5 % LS applied at full bloom, however, fruit quality and return bloom were not enhanced (Meland and Gjerde, 1996a; b). 10 % LS applied at 80 % bloom did not reduce fruit set on 'Bon Chrétien' pear (Dussi *et al.,* 2008). More research is needed to determine how LS rate and time of application influence thinning response on different pear cultivars (Garriz *et al.,* 2007).

4.2.3 Ethephon

Ethylene is believed to play a regulatory role in abscission (Sexton, 1997; Costa *et al.,* 2006). Ethylene-releasing substances such as ethrel and ethephon can be used in fruit production to reduce fruit set (Wertheim, 2000; Webster, 2002a). Ethephon is a well-known bloom and post-bloom thinning agent that gives variable results (Wertheim, 1997). It can be used to thin pear and apple flowers and/or fruitlets depending on time of application (Knight, 1982; Looney, 1983). A reduction in diffusible auxins is a prerequisite for a satisfactory thinning effect from ethylene (Ebert and Bangerth, 1982). Ethylene is known to reduce diffusible auxins by inhibiting IAA synthesis and transport as well as increasing IAA degradation (Sexton, 1997). Most activity is to be expected when natural tendency for flower and fruitlet drop is high. This is from the pink-bud stage to full bloom. Sensitivity declines to almost zero at petal fall and increases shortly before the "June drop" in pome fruit (Wertheim and Webster, 2005). However, early applications may be ineffective, 240 $mg.l^{-1}$ ethephon applied at the beginning of flowering did not reduce fruit set on 'Conference' (Wertheim, 2000).

Full bloom applications of 50, 100, 200 and 400 $mg.l^{-1}$ ethephon were evaluated on 'Winter Cole' pear. Fruit set tended to decline with increased rates of ethephon, but only 400 $mg.l^{-1}$ thinned adequately (Bound *et al.,* 1991). The same treatments applied 11 d.a.f.b. thinned less and when applied at both times, no extra thinning was observed from the thinning at full bloom (Bound *et al.,* 1991). Interestingly, when ethephon was applied at the higher rates of 200 and 400 $mg.l^{-1}$ 11 d.a.f.b., mean fruit weight did not respond to significant levels of fruit thinning. This suggests that later applications of higher rates of ethephon have a direct adverse effect on fruit growth (Bound *et al.,* 1991).

4.2.4 Conclusion on blossom thinning

Blossom thinning is a useful thinning strategy which has the distinct advantage of earlier fruit set reduction theoretically resulting in greater benefits to the grower, in terms of fruit size at harvest and return bloom. However, blossom thinning is a high risk strategy in agro-ecological zones characterised by high humidity at flowering time and late spring frosts. At rates required for acceptable blossom thinning, blossom desiccants are phytotoxic, injuring leaves (particularly the delicate spur leaves) and developing buds, and promote russet. Therefore, the reduction of fruit set is not always accompanied by a concomitant increase in fruit size, quality and return bloom, the main objectives of thinning fruit trees.

4.3 Post-bloom thinning

The advantage of post-bloom thinning over blossom thinning is that, it is carried out after the greatest risk of frost damage has elapsed (Webster, 2002b). Therefore, post-bloom thinning agents can be used in all fruit growing regions (Faust, 1989). Chemical post-bloom thinning agents have been shown to enhance fruit abscission in pears and are usually applied when the fruits are 10 to 15 mm in diameter, i.e. 10 to 25 d.a.f.b. (Faust, 1989; Webster, 2002b). Eight mechanisms have been proposed to explain the enhancement of fruit abscission by these thinning agents (Table 1). Post-bloom thinning agents act in a combination of two or more of these eight mechanisms (see Fig. 1), depending on tree conditions and climate (Table 2).

Table 1. Mechanisms proposed to explain the fruit thinning action of chemicals (Dennis, 2000).

1	Abortion or inhibition of embryo growth
2	Delay of abscission, increasing competition among fruits for nutrients
3	Inhibition of phloem transport to fruit
4	Reduction of sink strength of fruit/stimulation of sink activity in the bourse shoot
5	Inhibition of auxin (IAA) synthesis by seed
6	Inhibition of auxin (IAA) transport from the fruit
7	Stimulation of ethylene biosynthesis
8	Inhibition of photosynthesis/stimulation of dark respiration

The first visible signs of successful chemical post-bloom thinning of pears usually appear late October to early November in the Southern Hemisphere. The difference between the crop load on sprayed and unsprayed trees becomes less visible with time, but the fruit size of sprayed trees is often visibly superior (Marais, 1987). However, post-bloom thinning often has poor precision in terms of, when thinning occurs, the crop load achieved and distribution of fruits within the canopy (Webster, 2002a).

The efficacy of synthetic auxins, cytokinins and ethylene, as well as the insecticide carbaryl as post-bloom thinning agents has been evaluated on European pear cultivars and will be discussed individually in the following sections.

4.3.1 Auxins

The first thinners discovered were naphthaleneacetic acid (NAA) and its amide (NAD) (Dennis, 2000; Wertheim, 2000). These are the primary post-bloom thinning agents of pear trees (Looney, 1983; Bonghi *et al.,* 2002; Garriz *et al.,* 2004). The thinning action of these auxins was found by accident and was not expected, as auxins were known to retard abscission (Dennis, 2000; Wertheim, 2000). NAA and NAD are applied at rates up to 20 and 100 $mg.l^{-1}$, respectively. A number of theories to explain the mode of action of synthetic auxins when applied as post-bloom thinning agents have been suggested (Fig. 1; 2). Early observations that auxin applications reduce early fruit drop led to the suggestion that auxins first stimulated fruit set and then, because of increased competition between fruits for assimilates, a greater percentage of fruits abscised during the "June drop" (Gianfagna, 1987; Dennis, 2000). Early researchers believed that auxins stimulate fruitlet abscission by inducing embryo abortion in the seeds of developing fruits, thus reducing sink strength (Leopold**,** 1958; Dennis, 2000). However, it has since been proven that auxins also stimulate the abscission of seeded fruits, thus seed abortion does not explain the NAA/NAD-induced fruit abscission (Faust, 1989; Meland and Gjerde, 1996b; Dennis, 2000).

The ability of fruit to compete for assimilates is related to the magnitude of diffused IAA gradients (Bangerth, 2000; 2005). IAA was found to stimulate the differentiation of vascular tissues (Dengler, 2001), thus fruits with the highest rates of IAA diffusion will develop rapidly and better maintain vascular connections. It has been proposed that these synthetic

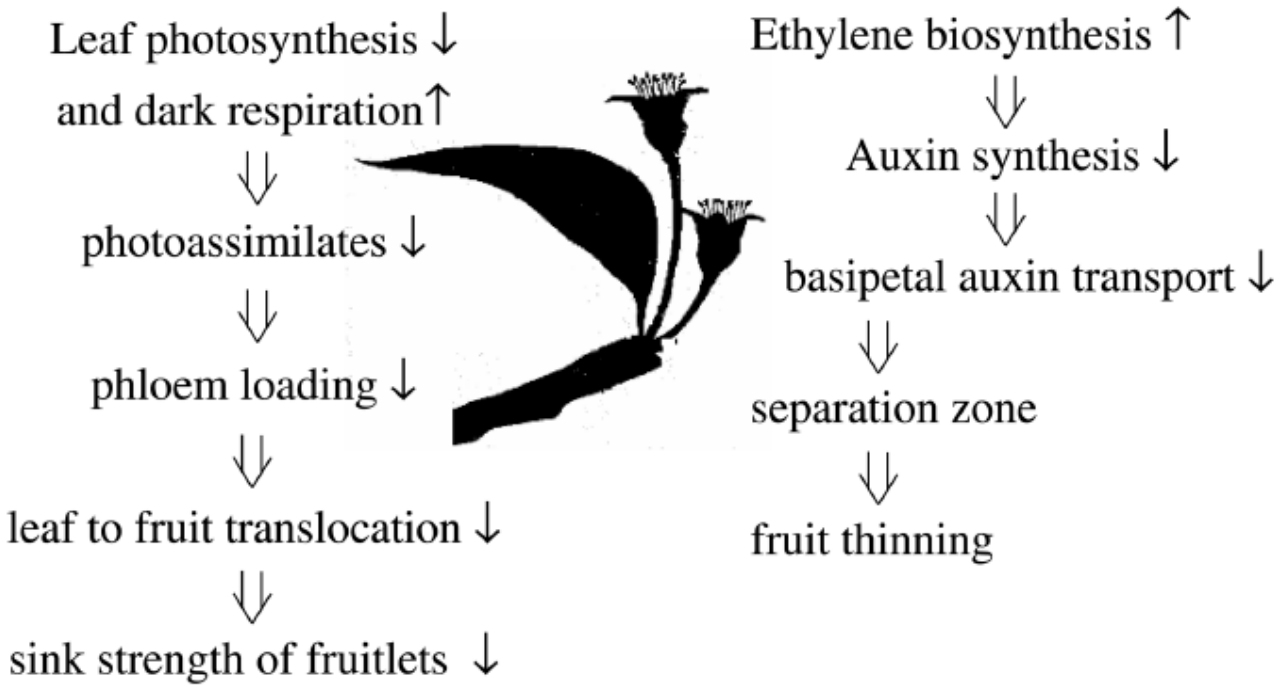

Fig. 1. Proposed mode of action of post-bloom thinning agents (reproduced with permission from Untiedt and Blanke (2001)).

Table 2. Tree and weather conditions affecting fruit thinning with chemicals (Williams and Edgerton, 1981).

Easy to thin when:	**Difficult to thin when:**
1. Bloom is heavy, especially after a heavy crop	1. Insects are active in orchards of cross-pollinated cultivars
2. Soil nitrogen and moisture are low or inadequate	2. Trees are in good vigour with terminal growth and no mineral deficiencies
3. Fruit spurs are low in vigour on the shaded inside of branches	3. Precocious trees come into fruiting with good vigour and mature bearing habit
4. Root systems are weak due to injury or disease	4. Fruits are developing on spurs and well lighted areas of the tree
5. Trees are young with many vigorous upright branches	5. Biennial bearing trees in the 'on' year
6. Trees are self pollinated or poorly pollinated	6. Trees that have horizontal or spreading fruiting branches
7. Fruit set appears heavy on easily thinned cultivars such as 'Delicious'	7. Fruit set is in singles rather than in clusters
8. Fruit sets in clusters rather than singles	8. Cultivars such as 'Golden Delicious', 'Fuji' or heavy setting spur-types
9. The cultivars tend to have a heavy 'June drop'	9. Ideal fruit growth conditions occur before and after thinning period
10. Bloom period is short and pollination is inadequate	10. Low humidity causes rapid drying of spray and decreasing absorption
11. High temperature is accompanied by high humidity before or after spraying	11. Mild temperatures occur after bloom without tree stress
12. Foliage is conditioned for increased chemical absorption by prolonged cloudy periods before spraying	12. Bloom is light and high leaf-to-fruit ratio occurs
13. Prolonged cloudy periods reduce photosynthesis before or after application of chemicals	13. Limbs and/or spurs are slightly girdled from winter injury
14. When stress and endogenous ethylene production are high	14. When stress and endogenous ethylene production are low

auxins (NAA and NAD) may temporarily disrupt the efflux of diffusible auxin (IAA) from weaker, lateral fruitlets, which directly restricts their assimilate supply (Bangerth, 2000; Webster, 2002a). Exogenous auxin applications also are believed to stimulate ethylene production in many plant tissues. Ethylene inhibits the synthesis and translocation of IAA by fruits (Fig. 1), thus reducing sink strength and ultimately inducing fruit abscission (Yang, 1980; Ebert and Bangerth, 1982; Faust, 1989; Dennis, 2000; Webster, 2002b). Auxins are also believed to cause a temporary reduction in photosynthesis and the movement of assimilates to the fruits by reducing the conductance of CO_2 in the mesophyll (Untiedt and Blanke, 2001; Jackson, 2003), resulting in the abscission of weaker fruitlets due to nutrient starvation (Bangerth, 2000).

4.3.1.1 Naphthaleneacetic acid

Several trials have been conducted to evaluate the efficacy of NAA on thinning European pear cultivars. Results obtained thus far appear largely dependent on cultivar, environmental conditions, rate and time of application (Wertheim, 1973; 2000; Bonghi *et al.,* 2002). NAA is used from full bloom onwards, in some cases, as late as "June drop" (Bertelsen, 2002a). Earlier applications are more effective than late applications in reducing fruit set (Reginato and Gonzalez, 1998). However, desired results are not always assured when using NAA, and a reduction in crop load is not always accompanied by a concomitant increase in fruit size (Wertheim, 1997; Bertelsen, 2002a). Studies have revealed that NAA is temperature dependant, rendering it an unreliable thinning agent where spring temperatures are low and variable (Wertheim, 1997; Moran and Southwick, 2000; Bertelsen, 2002a).

Since NAA was the first thinning agent to be used on European pear cultivars, a significant number of published works on its absorption are available. Absorption studies have indicated that less than half of the material applied to the leaves is absorbed and this uptake is dependant on various factors (Lombard, 1967). Absorption of NAA can be increased by preconditioning the foliage with low light intensity and low temperatures prior to application (Greene and Bukovac, 1977; Schönherr *et al.,* 2000). Conditions during application, such as increased air temperature and increased drying time by high relative humidity (RH), were found to increase NAA absorption (Greene and Bukovac, 1972; Schönherr *et al.,* 2000). NAA penetration through the pear leaf cuticle is better at 20 °C than at 10 °C and at 100 %

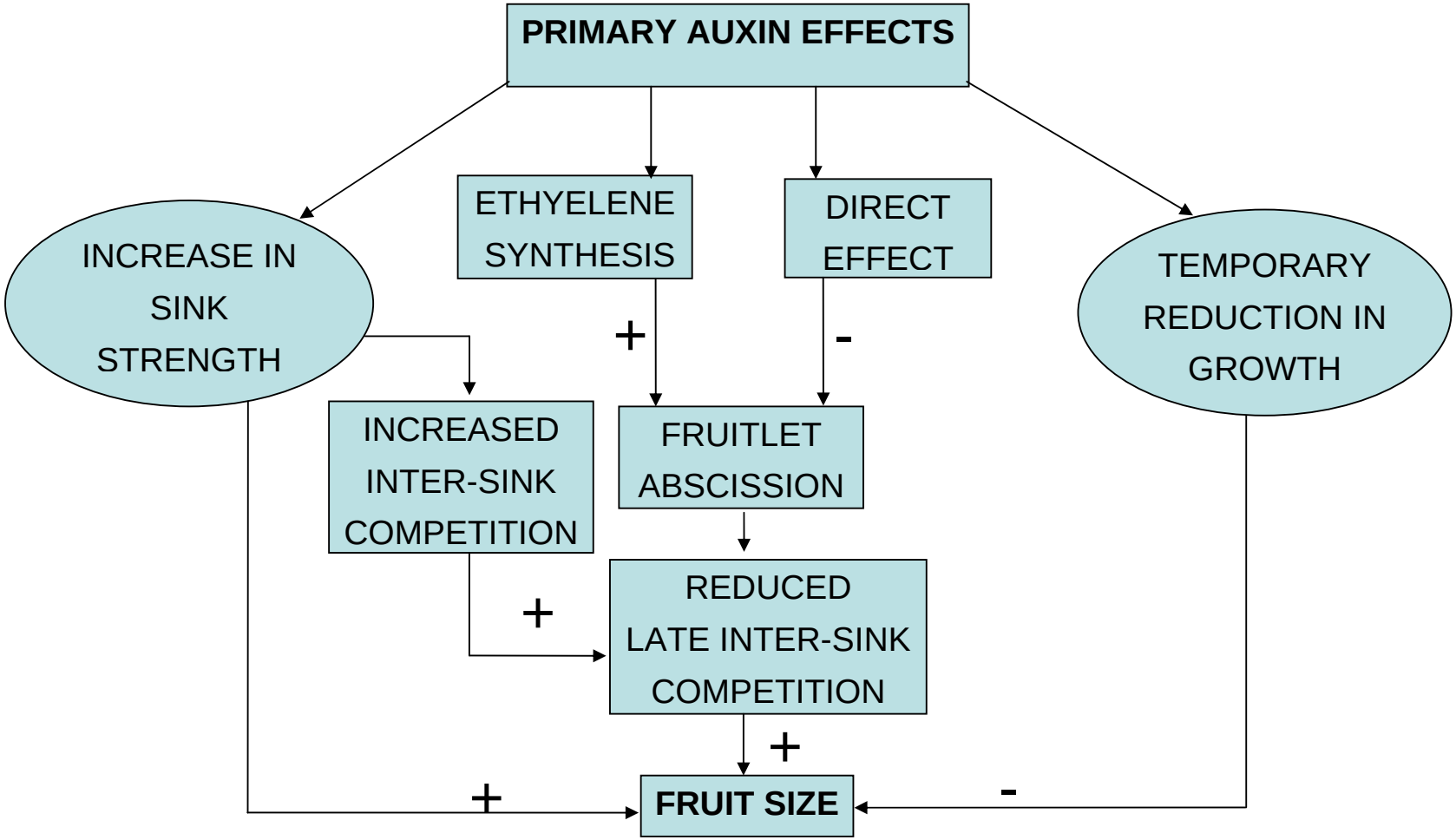

Fig. 2. Diagram adapted from Guardiola (1988) showing the primary effects of synthetic auxins on fruit growth rate, abscission and final fruit size for citrus.

RH than 55 % RH (Greene and Bukovac, 1974). Highest rates of penetration were obtained when solutions were buffered at pH 4. At this pH, a significant proportion of NAA is non-ionized and in this form enters the cuticle. This also applies when an accelerator adjuvant is added to the spray solution. NAA must be applied in the evening because it is destroyed by ultra-violet light (Lombard, 1967; Schönherr *et al.,* 2000).

In the USA, 15 to 20 $mg.l^{-1}$ NAA plus a surfactant (usually Tween-20) applied 15 to 21 d.a.f.b. is recommended on the commercially important 'Bon Chrétien' pears (Williams, 1973; Williams and Edgerton, 1981). On 'Abate Fetel', 10 $mg.l^{-1}$ NAA applied 17 and 27 d.a.f.b., reduced crop load and increased fruit size, without any detrimental effects on fruit quality and firmness (Garriz *et al.,* 2004). Fruit set on 'Clara Frijs' has been found to decrease linearly in response to increasing NAA rates (Meland and Gjerde, 1996a). On 'Clara Frijs' pear, 45 $mg.l^{-1}$ NAA increased average fruit size, the number of fruit larger than 65 mm and return bloom, although not significantly (Bertelsen, 2002a). NAA can promote flower bud formation (Tromp, 2000) by reducing fruit set (Williams, 1994; Wertheim, 2000), thus reducing the amount of diffusible seed-produced GAs which inhibit flower-bud formation (Davenport, 2000; Tromp, 2000).

However, auxins applied early tend to inhibit flower induction (Westwood, 1993), by enhancing the inhibitory effect of gibberellins (Bubán, 1996). When 10, 15 or 20 $mg.l^{-1}$ NAA applications at 8 to 10 mm fruit size were evaluated on 'Conference' pear, the efficacy of NAA increased with the rate (Vilardell *et al.,* 2005). The highest rate reduced fruit set by 28 % without increasing the average fruit weight. NAA at 20 $mg.l^{-1}$ was detrimental to return bloom. Wertheim (2000) noted a linear reduction in fruit set and a linear increase in fruit size with NAA rates of 10, 20 or 40 $mg.l^{-1}$ on 'Conference' pear. The highest rate was the most effective treatment. When applied 4, 12 or 28 d.a.f.b., there was a linear reduction in fruit set and a linear increase in fruit size. The best results were observed when NAA was applied 28 d.a.f.b. (Wertheim, 2000).

Fruit trees often vary in their sensitivity to NAA, therefore recommended rates are often cultivar specific (Williams, 1973; Bertelsen, 2002a). When applied to 'Rosada' and 'Conference' pear, 5 or 10 d.a.f.b., NAA was totally ineffective in reducing crop load and increasing fruit size on 'Rosada'. On 'Conference', 5 $mg.l^{-1}$ NAA applied 5 d.a.f.b. increased fruit set, while the same rate applied 10 d.a.f.b. reduced fruit set and increased fruit size (Bonghi *et al.,* 2002). NAA sprays at 10 to 20 $mg.l^{-1}$ have been shown to thin the pear cultivar 'Winter Nellis', but in contrast the same sprays increased fruit set on 'Bon Chrétien' (Reginato and Gonzalez, 1998). Dussi *et al.* (2008) also found 20 $mg.l^{-1}$ NAA ineffective in reducing fruit set on 'Bon Chrétien'. Due to its dependency on climatic conditions, NAA is not a reliable chemical thinning agent. Its amide, NAD, is reportedly a more reliable thinning agent under conditions of low and variable spring temperatures (Jackson and Looney, 1999; Wertheim, 2000; Webster, 2002a).

4.3.1.2 Naphthylacetamide

NAD is a more reliable post-bloom thinning agent than NAA, in areas with variable weather during early stages of fruit growth (Wertheim, 2000; Webster, 2002a). NAD is a milder thinning agent than NAA (Williams and Edgerton, 1981), which performs better on 'Bon Chrétien' and is recommended under conditions favourable for fruit set, while NAA is recommended under less favourable conditions (Lombard, 1967). NAD does not have any serious detrimental effects on 'Bon Chrétien' pear quality at harvest or after storage (Meheriuk and Looney, 1985). For an optimal effect, NAD should be applied soon after flowering (2 to 5 d.a.f.b.). Increasing temperature, rate and addition of wetters enhance the uptake of NAD by pear leaves (Wertheim, 2000).

On 'Bon Chrétien' pear, 10 or 15 $mg.l^{-1}$ NAD applied 15 to 21 d.a.f.b. effectively reduced crop load and increased fruit size (Lombard, 1967; Williams and Edgerton, 1981). Results obtained by Bonghi *et al.* (2002) in Italy on 'Conference' and 'Rosada' pear, indicate that 15 $mg.l^{-1}$ NAD applied 5 d.a.f.b. is a suitable post-bloom thinning agent (better than ethephon and NAA) for reducing crop load and increasing fruit size. Positive thinning results were observed in the Ceres production area of

South Africa on 'Bon Chrétien' where 20 mg.l^{-1} NAD applied 5 d.a.f.b. resulted in a 12 % reduction in total yield. This was accompanied by a 78 % increase in revenue per ton and a 44 % increase in revenue per hectare (Marais, 1987).

However, like NAA, the effects of NAD are often dependent on cultivar and a reduction in fruit set is not always accompanied by an increase in fruit size. NAD at 20 mg.l^{-1} reduced crop load, but did not increase fruit size on 'Coscia' pear (Stern and Flaishman, 2003). NAD may cause leaf damage if applied late and/or at rates higher than 25 mg.l^{-1} (Lombard, 1967; Wertheim, 2000). At these rates, NAD may also cause premature ripening and core breakdown of 'Bon Chrétien' pear fruits (Lombard, 1967). On 'Conference', NAD has reportedly caused leaf damage and is thus not recommended for use in some countries e.g. The Netherlands (Wertheim and Webster, 2005). NAD is a promising thinning agent for European pear cultivars and requires further evaluation for commercial use in South Africa.

4.3.2 Cytokinins

Cytokinins are known to reduce crop load and promote return bloom (Bubán, 2000). They also stimulate cell division in the developing fruit, thus possibly increasing fruit size independent of thinning (Looney, 1983; 1993; Westwood, 1993). Flaishman *et al.* (2001) suggested that cytokinins are a major factor limiting fruit growth and final size in small fruited pear cultivars. Cytokinins promote fruit growth by stimulating and prolonging the phase of mitotic cell division in developing fruit (Flaishman *et al.,* 2005; Shargal *et al.,* 2006). Cytokinins promote flower bud formation and flower differentiation, by ensuring sufficient meristematic activity for the differentiation of flower parts, which leads to high quality reproductive buds (Luckwill, 1970; Wertheim, 1990; Taiz and Zeiger, 2002). Results from recent trials suggest that the synthetic cytokinins, 6-benzyladenine (BA), CPPU ((2-chloro-4-pyridyl)-N-phenylurea) and thidiazuron (TDZ) are effective post-bloom thinning agents of pear trees.

4.3.2.1 6-benzyladenine

6-benzyladenine (BA) was the first compound to be discovered with cytokine activity (Bubán, 2000). It is the most favoured cytokinin for fruit thinning, although it may thin variably and unselectively (Wertheim, 1997). BA was tested as a fruit thinner in the early 1990s, resulting in the introduction of a commercial product, Accel ™ (Valent Biosciences), which also contains a small amount of GA_{4+7}. It was a weak thinner and has been replaced by MaxCel ™ (Valent Biosciences), which contains more BA and is more effective (Bubán, 2000; Dennis and Hull, 2003).

BA is applied when fruitlets are between 7 and 12 mm (most often 10 to 12 mm) in diameter i.e. 14 to 21 d.a.f.b., at rates of 25 to 200 $mg.l^{-1}$, most often 50 to 100 $mg.l^{-1}$ (Bubán, 2000; Bertelsen, 2002a). Like most chemical thinning agents, the effect of BA is temperature dependent (Bubán, 2000). For BA to be effective, minimum temperatures of around 18 °C are required. BA is not toxic to several important beneficial organisms, while its toxicity to mammalian and arthropod species is low (Bound *et al.,* 1997; Bubán, 2000). BA has therefore become more acceptable as a post-bloom thinning agent of pears (Bubán, 2000).

BA increases fruit size via two effects, firstly (and indirectly), thinning by stimulating and/or amplifying fruit abscission and secondly (and directly), fruit enlargement by stimulating and/or prolonging mitotic division of parenchyma cells (Yuan and Greene, 2000; Stern and Flaishman, 2003). Three mechanisms have been suggested to explain the manner in which BA promotes fruit abscission. These are:

1. Stimulating growth of lateral side shoots, such as the bourse shoot (Faust, 1989; Williams, 1994). IAA transport out of these newly released lateral shoots may correlatively inhibit IAA transport from fruit leading to the abscission of some of the fruitlets (Bangerth, 2000; Schröder and Bangerth, 2006).

2. Temporarily decreasing net photosynthesis and increasing dark respiration, which leads to limited carbohydrate supply to the fruitlets (Table 1; Fig. 2), resulting in the abscission of smaller and weaker lateral fruits (Yuan and Greene, 2000; Wertheim and Webster, 2005).

3. Increasing ethylene production (Greene 1989; Li and Bangerth, 1992), which inhibits the synthesis and translocation of IAA by fruitlets (Table 1; Fig. 2), reducing sink strength and resulting in the abscission of smaller and weaker lateral fruits (Ebert and Bangerth, 1982).

However, some researchers are of the opinion that BA does not affect leaf assimilation (Stopar *et al.,* 1997; Wertheim, 2000), whereas, the magnitude of BA-induced ethylene production cannot be responsible for the thinning response (Greene 1989; Stopar *et al.,* 2000). BA increases fruit size directly by stimulating and prolonging cell division, thus increasing sink strength (Bubán, 2000). Increased assimilate influx to BA-treated organs (i.e. sink effect) has been reported, with treatments at earlier stages of fruit growth being more effective in promoting assimilate efflux from leaves adjacent to the application sites (Bubán, 2000; Roitsch and Ehne, 2000).

On 'Clara Frijs', 100 $mg.l^{-1}$ BA applied at 12 mm fruit size, reduced fruit set and fruit density and increased average fruit size and return bloom (Bertelsen, 2002a). High cytokinin levels during flower induction are known to increase the number of reproductive buds induced and high levels of cytokinins during the time of flower initiation and differentiation will improve flower quality (Wertheim, 1990; Reynolds, 2004). 'Packham's Triumph' was effectively thinned with BA at 100 to 150 $mg.l^{-1}$ applied 10 to 40 d.a.f.b. (Bound and Mitchell, 2002b). On 'Bon Chrétien', 150 to 200 $mg.l^{-1}$ BA reduced crop load and improved fruit size (Dussi *et al.,* 2008). The efficacy of BA is largely dependent on rate. BA at 100 $mg.l^{-1}$ applied 28 d.a.f.b. was not effective in reducing fruit set on 'Conference' pear, whereas 200 $mg.l^{-1}$ BA applied 28 d.a.f.b. reduced fruit set by 66 % (Wertheim, 2000; Vilardell *et al.,* 2005).

The interesting response to BA is the increase in fruit size achieved in some cultivars and seasons without any apparent reduction in crop load (Wertheim, 2000; Bubán, 2000; Webster, 2002a). On 'Spadona' and 'Coscia', 100 $mg.l^{-1}$ BA applied 14 d.a.f.b. increased fruit size without a negative influence on fruit shape, seed number and return bloom and yield the following year (Stern and Flaishman, 2003). A small reduction in fruit set was observed in 'Spadona', whilst in 'Coscia', the treatment was accompanied by heavy thinning. The increase in size of 'Spadona' fruits can be attributed to an increase in cell number as a result of the exogenous cytokinin. BA prolongs the phase of mitotic cell division in the cortex of developing fruits (Shargal *et al.,* 2006).

Experimental results have shown that BA is an efficient post-bloom thinner of European pear cultivars when applied at 8 to 12 mm fruit size at rates of 100 to 200 $mg.l^{-1}$.

4.3.2.2 ((2-chloro-4-pyridyl)-N-phenylurea)

CPPU applied at rates of 10 to 20 $mg.l^{-1}$, 7 to 21 d.a.f.b., increased fruit size on 'Spadona' and 'Coscia' pear without reducing fruit number, seed content and return bloom and without any negative influence on fruit shape (Flaishman *et al.,* 2001). 10 $mg.l^{-1}$ CPPU increased fruit size by 40 % on 'Spadona' and 80 % on 'Coscia' pear trees, with an increase of about 50 % in the total yield of each cultivar.

Stern *et al.* (2002) noted a quadratic increase in fruit size with timing of CPPU applications of 10 and 20 $mg.l^{-1}$ on 'Spadona' pear. CPPU increased fruit size when applied at full bloom 7, 14 and 21 d.a.f.b., but the most effective application time appeared to be 14 d.a.f.b. with its efficacy decreasing greatly at 28 d.a.f.b. CPPU also had no effect on crop load, fruit shape and seed number in this trial.

4.3.2.3 Thidiazuron

Thidiazuron (TDZ) increased fruit size of 'Spadona' and 'Coscia' pears at rates ranging from 20 to 40 $mg.l^{-1}$ (Stern *et al.,* 2003). When applied 14 d.a.f.b., the 20 and 30 $mg.l^{-1}$ rates performed best. TDZ increased fruit size without causing any deformation and had no effect on seed number and return bloom on 'Spadona' and 'Coscia' pear (Stern *et al.,* 2003). TDZ caused a large increase in fruit size with only a little crop load reduction, therefore, the increase in fruit size was attributed mainly to a direct effect of TDZ, which prolongs the phase of cell division in the fruit cortex (Flaishman *et al.,* 2001; Stern *et al.,* 2002). CPPU and TDZ are both phenylureas, therefore it is not surprising that they have a similar impact on fruit growth, although TDZ has a small thinning effect which is absent with CPPU (Flaishman *et al.,* 2001; Stern *et al.,* 2003; Flaishman *et al.,* 2005). CPPU and TDZ are the most active cytokinins, however, they may reduce flower bud formation (Looney, 1993; Wertheim, 1997). CPPU and TDZ are currently not approved for commercial use on pears (Dennis, 2000; Wertheim, 2000).

Cell division during the early stage of fruit development has a major influence on final fruit size (Westwood, 1993). As early fruit cell division is normally influenced by endogenous growth hormones especially cytokinins (Looney, 1983), exogenous applications of cytokinins can increase fruit size beyond that expected from the degree of thinning in some situations (Wertheim, 2000; Bangerth, 2004). BA, CPPU and TDZ had no effect on seed numbers, therefore, the increase in fruit size is not related to a change in the number of seeds (Flaishman *et al.,* 2001; Stern and Flaishman, 2003; Stern *et al.,* 2003; Dussi *et al.,* 2008). Seeds are a source of endogenous cytokinins (Flaishman *et al.,* 2001; Bangerth, 2005).

Cytokinins are gradually becoming the most important post-bloom thinning agents because they are effective and occur naturally in plants. However, there is need for further research to better understand their mode of action so as to improve their efficacy.

4.3.3 Ethephon

Ethephon may also be used as post-bloom thinning agent of pears (Wertheim and Webster, 2005). Ethephon is a growth regulator which is practically stable in a solution with a pH below 4, however, at higher pH values, it breaks down to ethylene, phosphatic and hydrochloric ions. The cell cytoplasm has a pH higher than 4, thus ethephon provides the plant tissues with ethylene (Nicotra, 1982). Ethylene is believed to work by inhibiting the synthesis and translocation of IAA by fruits (Fig. 1), thus reducing sink strength (Ebert and Bangerth, 1982) and ultimately inducing the separation zone in the peduncle which causes fruit drop (Roberts *et al.,* 2002). 500 $mg.l^{-1}$ ethephon applied 30 d.a.f.b. inhibited and interfered with the synthesis and translocation of IAA in pears (Ebert and Bangerth, 1982). According to Untiedt and Blanke (2001), ethylene may inhibit canopy photosynthesis (Fig. 1), thus increasing inter-sink competition, resulting in the abscission of weaker fruits due to nutrient starvation.

Results obtained by Bonghi *et al.* (2002) in Italy on 'Conference' and 'Rosada', indicated that ethephon was generally more effective than NAA showing thinning activity in both cultivars when applied at two rates, 200 and 600 $mg.l^{-1}$, 5 and 10 d.a.f.b., respectively. However, there was huge variability in its thinning effect (Bonghi *et al.,* 2002). This is probably due to the important effect of temperature on its uptake and degradation (Wertheim and Webster, 2005). 500 $mg.l^{-1}$ ethephon applied 5 and 12 d.a.f.b. reduced crop load and increased fruit size and return bloom on 'Conference' pear trees (Knight and Browning, 1986). Ethephon improves return bloom in pear, possibly by inhibiting shoot growth (Wertheim, 2000).

However, late applications are ineffective and may actually promote fruit set. 250 to 500 $mg.l^{-1}$ ethephon applied 28 to 42 d.a.f.b. increased fruit set on 'd'Anjou' pear trees (Williams, 1977). On 'Doyenné du Comice' pear, fruit set was increased by 50 %, following ethephon application 15 d.a.f.b. at a rate of 400 $mg.l^{-1}$, but reduced fruit set the following season (McArtney and Wells, 1995). This highlights the complicated nature of ethylene action. Ethephon is therefore an unreliable post-bloom thinning

agent on European pear cultivars.

4.2.4 Carbaryl

Carbaryl is an insecticide that can also be used as a post-bloom thinning agent on pears (Knight, 1986; Williams, 1994). Carbaryl acts as a post-bloom thinner when applied 10 to 25 d.a.f.b. It lacks action when applied later, at 40 or more d.a.f.b. (Tukey, 1981). Carbaryl is considered more consistent than NAD, as a post-bloom thinning agent (Wertheim, 2000). It induces endogenous ethylene production under warm conditions (Williams, 1994), which stimulates fruit drop (Sexton, 1997). If the temperature is low, seed abortion may occur without much ethylene production to stimulate fruit drop (Burts and Kelly, 1960; Griggs *et al.,* 1962; Williams, 1994). However, no relationship was found between seed abortion and fruit abscission (Dennis, 2000).

Carbaryl is believed to be only effective when applied directly to the fruit (Knight 1983, Bangerth, 2000), where it is believed to stimulate fruit abscission by reducing IAA export (Fig.1) from those fruit (Ebert and Bangerth 1982; Bangerth, 2000). Carbaryl selectively thins within the cluster, reducing the proportion of clusters that carry more than one fruit, as well as reducing the proportion of clusters that lose all their fruit (Knight, 1986). It therefore thins the crop in a way most advantageous to the production of large fruits, removing lateral fruitlets from the cluster in preference to the king fruit, resulting in an increased proportion of king fruits at harvest .

However, carbaryl is not an effective post bloom thinning agent of pears (Lombard, 1967; Wertheim, 2000). When applied in high or low volume sprays it did not serve as thinning agent of ‘Bon Chrétien’ in the Sacramento valley, California (Griggs *et al.,* 1962). Carbaryl may cause russet on European pears (Griggs *et al.,* 1962; Williams, 1994; Link, 2000). It does not comply with Integrated Pest Management guidelines as it harms beneficial organisms and bees. Carbaryl has thus lost its registration in most major fruit growing countries (Williams, 1994; Webster, 2002a).

Combination sprays

Some pear cultivars are difficult to thin using chemical thinning agents. This is probably due to various genetic factors such as parthenocarpy as well as endogenous cytokinin levels during the critical phase of cell division (Flaishman *et al.,* 2001). According to Wertheim (2000), combinations of two thinning agents can cause more thinning than compounds used separately. Combining two different thinning agents such as BA with auxins (NAA and NAD) will can reduce fruit size and improve fruit size significantly on difficult-to-thin pear cultivars such as 'Conference'. This is because auxins have been shown to significantly reduce fruit set on 'Conference' (Wertheim, 2000; Bonghi *et al.,* 2002), while BA applications can improve fruit size without reducing fruit set (Wertheim, 2000; Bubán, 2000; Webster, 2002a; Stern and Flaishman, 2003). The BA and NAA combination significantly reduced the number of small fruit and improved average fruit weight of two small fruited apple cultivars 'Elstar' and 'Gala' in Poland (Basak, 2004) and America (Bukovac *et al.,* 2008). However, according to Greene and Autio, 1994, BA and NAA may greatly increase the occurrence of pygmy fruit in apple. Combination sprays of BA (200 $mg.l^{-1}$) with NAA significantly reduced fruit set and improved fruit size of 'Conference' pear (Vilardell *et al.,* 2005). However, the 200 $mg.l^{-1}$ BA application alone was more effective. In attempts to improve fruit thinning in hard-to-thin pear cultivars, it might be necessary to explore the possibility of different dosage combinations of BA and NAA (Wertheim, 2000; Vilardell *et al.,* 2005).

Conclusion

Fruit thinning is an important orchard management practice, to ensure commercially-acceptable fruit size at harvest and improving return bloom the following season, thus ensuring high, regular yields of superior quality fruit. Thinning by hand is not practically feasible on a commercial scale because of the unavailability of labour as well as high labour costs. Mechanical thinning on the other hand, lacks precision, is indiscriminate and often causes unacceptable physical damage to the developing

fruits, buds and foliage. Chemical thinning is thus the most applicable method to reduce crop load on a commercial scale, as it requires less labour, causes relatively little damage to fruits and foliage and is relatively cheap. Bloom thinning agents, theoretically are more suitable than those applied post bloom in reducing fruit set early, thus improving fruit size and return bloom. However, the problem with these blossom thinning agents is their unacceptable levels of phytotoxicity on pear trees in areas which experience rainfall and/or high humidity during the bloom period. This often results in over-thinning without any accompanying increase in fruit size or return bloom due to leaf injury. Many popular pear cultivars are not very fertile (often requiring GA sprays at bloom to induce set) and are susceptible to late spring frosts. Growers are therefore reluctant to use bloom thinning agents as they want to guarantee adequate fruit set before reducing crop load. Blossom thinning agents are thus only applicable in drier regions less prone to late spring frosts. Post-bloom thinning agents are the most suitable chemical thinners for European pears as they are applied after the risk of frost has elapsed and adequate fruit set is guaranteed. Based on results from recent thinning trials on European pear cultivars, the milder and effective thinners, 6-benzyladenine (BA) and naphthylacetamide (NAD) seem to be the most effective means to reduce crop load, and improve fruit size and return bloom.

Literature cited

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

Bangerth, F. 2004. Internal regulation of fruit growth and abscission. *Acta Hort*. 636: 235 - 248.

Bangerth, F. 2005. A more holistic view on the hormonal interactions among different organs in a fruit tree. *Acta Hort*. 671: 25 - 36.

Bangerth, F. 2006. Flower induction in perennial fruit trees: still an enigma? *Acta Hort*. 727: 177 - 196.

Basak, A. 2004. Fruit thinning by using benzyladenine (BA) with ethephon, ATS, NAA, urea and carbaryl in some apple cultivars. *Acta Hort*. 653: 99 - 106.

Bergh, O. 1985. Effect of the previous crop on cortical cell number of *Malus domestica* cv. 'Starking Delicious' apple flower primordia, flowers and fruit. *S. Afr. J. Plant Soil*. 2: 1991 - 1996.

Bertelsen, M.G. 2002a. Benzyladenine and other thinning agents for pear cv. 'Clara Frijs'. *J. Amer. Pomol. Soc*. 56: 149 - 155.

Bertelsen, M.G. 2002b. Effect of crop load in previous year on fruit size of pear cultivar 'Clara Frijs'. *Acta Hort*. 596: 777 - 781.

Bonghi, C., Poja, M. and Ramina, A. 2002. Ethephon, NAA and NAD as chemical thinners of pear fruitlets. *Acta Hort*. 596: 717 - 722.

Bound, S.A. and Mitchell, L. 2002a. The effect of blossom desiccants on crop load of 'Packham's Triumph' pear. *Acta Hort*. 596: 729 - 733.

Bound, S.A and Mitchell, L. 2002b. A new post-bloom thinning agent for 'Packham's Triumph' pear. *Acta Hort*. 596: 793 - 796.

Bound, S.A. and Jones, K.M. 2004. Ammonium thiosulphate as a blossom thinner of 'Delicious' apple, 'Winter Cole' pear and 'Hunter' apricot. *Austr. Jour. Exp. Agr*. 44: 931 - 937.

Bound, S.A., Jones, K.M. and Koen, T. B. 1991. Ethephon concentration and timing effects on thinning of 'Winter Cole' pear. *Austr. Jour. Exp. Agr*. 31: 133 - 136.

Bound, S.A., Jones, K.M. and Oakford, M.J. 1997. Post-bloom thinning with 6-benzyladenine. *Acta Hort.* 463: 493 - 499.

Bubán, T. 1996. Flower development and formation of sexual organs. pp. 3 - 54. In: Nyéki, J. and Soltész, M. (Eds.), Floral biology of temperate zone fruit trees and small fruits. Akadémiai Kiadó. Budapest.

Bubán, T. 2000. The use of benzyladenine in orchard fruit growing: a mini review. *Plant Growth Regul.* 32: 381- 390.

Bukovac, M.J., Sabbatini, P., Schwallier, P.G. and Schroeder, M. 2008. Characterizing the interaction between NAA and BA on apple fruit abscission and development. *HortScience* 43: 1794 - 1801.

Burts, E.C. and Kelly, S.G. 1960. Seed abortion and fruit drop in 'Bartlett' pear caused by Sevin. *Jour. Econ. Ent*. 53: 956 - 957.

Buszard, D. and Schwabe, W.W. 1995. Effect of previous crop load on stigmatic morphology of apple flowers. *J. Am. Soc. Hort. Sci.* 120: 566 - 570.

Byers R.E., Costa, G. and Vizzotto, G. 2003. Flower and fruit thinning of peach and other prunus. pp. 351 - 392. In: Janick, J. (Ed), Hort. Rev 28. Wiley J. and Sons Publishers. New Jersey.

Callejas, R. and Bangerth, F. 1998. Is auxin export of apple fruit an alternative signal for inhibition of flower bud induction? *Acta Hort*. 463: 271 - 277.

Costa, G., Dal Cin, V. and Ramina, A. 2006. Physiological, molecular and practical aspects of fruit abscission. *Acta Hort*. 727: 301 - 310.

Coetzee, J.H. and Theron, K.I. 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. *J. S. Afr. Soc. Hort. Sci*. 9: 13 - 17.

Dal Cin, V., Danesin, M., Ramina, A., Dorigoni, A., Boschetti, A. and Ruperti, B. 2005. Fruit abscission as related to fruit quality. *Acta Hort*. 682: 781 - 788.

Davenport, T.L. 2000. Processes influencing floral initiation and bloom: phytohormones in a conceptual flowering model. *HortTech.* 10: 733 - 739.

Davis, R.A. 1928. Fruit growing in South Africa. Central News Agency.pp. 215 - 233.

Dengler, N. 2001. Regulation of vascular development. *J Plant Growth Regul.* 20: 1 - 13.

Dennis, F.G. 2000. The history of fruit thinning. *Plant Growth Regul.* 31: 1 - 16.

Dennis, F.G. and Hull, J. 2003. Deciduous tree fruit. *HortScience.* 38: 901 - 910.

Dennis, F.G., Edgerton, L. and Parker, K.G. 1970. Effects of gibberellin and alar sprays upon fruit set, seed development, and flowering of 'Bartlett' pear. *HortScience* 5: 158 - 160.

Dussi, M.C., Sugar, D. and Wrolstad, R.E. 1995. Characterizing and quantifying anthocyanins in red pears and the effect of light quality on fruit colour. *J. Am. Soc. Hort. Sci*. 120: 785 - 789.

Dussi, M.C., Giardina G., Reeb, P. and Gastiazoro, J. 2008. Thinning programs in pears cv. Williams. *Acta Hort* (*accepted for publication*).

Ebert, A. and Bangerth, F. 1982. Possible hormonal modes of action of three apple thinning agents. *Scientia Hort*. 16: 343 - 356.

Fallahi, F. and Willemsen, K.M. 2002. Blossom thinning of pome and stone fruit. *HortScience* 37: 474 - 477.

Faust, M. 1989. Physiology of temperate zone fruit trees. Wiley. New York. pp. 169 - 234.

Flaishman, M.A., Shargal, A. and Stern, R.A. 2001. The synthetic cytokinin CPPU increases fruit size and yield of 'Spadona' and 'Coscia' pear (*Pyrus communis* L.). *J. Hort. Sci. Biotechnol.* 76: 145 - 149.

Flaishman, M., Shargal, A., Shilzerman, L. Lev-Yadun, S., Stern, R.A. and Grafi, G. 2005. The synthetic cytokinins CPPU and TDZ prolong the phase of cell division in developing pear (*Pyrus communis* L.) fruit. *Acta Hort.* 671: 151 - 157.

Garriz, P.I., Alvarez, H.L. and Colavita, G.M. 2004. Fruitlet thinning of the pear cultivar 'Abbé Fetel' with naphthaleneacetic acid. *Acta Hort*. 636: 325 - 330.

Garriz, P.I., Alvarez, H.L., Colavita, G.M. and Gajdos, M.S. 2007. Thinning response of 'Abbé Fetel' pear to lime sulphur. *J. Appl. Hort.* 9: 46 - 49.

Gianfagna T.J. 1987. Natural and synthetic growth regulators and their use in horticultural and agronomic crops pp. 614 - 635. In Davies, P.J. (Ed.), Plant hormones and their role in plant growth and development. Nijhoff. Dordrecht.

Gil, G.F., Martin, G.C. and Griggs, W.H. 1972. Fruit set and development in the pear: extractable endogenous hormones in parthenocarpic and seeded fruits. *J. Am. Soc. Hort. Sci.* 97: 731 - 735.

Gil, G.F., Martin, G.C. and Griggs, W.H. 1973. Fruit set and development in the pear: diffusible growth substances from seeded and seedless fruits. *J. Am. Soc. Hort. Sci.* 98: 51 - 54.

Greene, D.W. 1989. Regulation of fruit set in tree fruits with plant growth regulators. *Acta Hort*. 239: 323 - 334.

Greene, D.W. 1999. Reducing floral initiation and return bloom in fruit trees-applications and implications in fruit production: pome fruit (abstract). *HortScience* 34: 561.

Greene, D.W. 2000. Reducing floral initiation and return bloom in pome fruit trees-applications and implications. *HortTech*. 10: 740 - 743.

Greene, D.W. and Autio, W.R. 1994. Combination sprays with benzyladenine to chemically thin spur-type 'Delicious' apples. HortScience 29:887-890.

Greene, D.W. and Bukovac, M.J. 1972. Penetration of naphthaleneacetic acid into pear (*Pyrus communis* L.) leaves. *Plant and Cell Physiol.* 13: 321 - 330.

Greene, D.W. and Bukovac, M.J. 1974. Stomatal penetration: effect of surfactants and role in foliar absorption. *Amer. Jour. Bot.* 61: 100 - 106.

Greene, D.W. and Bukovac, M.J. 1977. Foliar penetration of naphthaleneacetic acid: enhancement by light and role of stomata. *Amer. Jour. Bot.* 64: 96 - 101.

Griggs, W.H. and Iwakiri, B.T. 1961. Effects of gibberellic acid and 2,4,5-trichloro-phenoxyproprionic acid sprays on Bartlett pear trees. *Proc. Amer. Soc. Hort. Sci.* 77:73 - 89.

Griggs ,W.H., Iwakiri, B.T. and Madsen, H.F. 1962. Effect of dilute and concentrated sprays of 1-naphthyl-N- methylcarbamate (Sevin) on fruit set and seed content of 'Bartlett' pears. *Proc. Amer. Soc. Hort. Sci.* 81: 93 - 97.

Griggs, W.H., Martin, G.B. and Iwakiri, B.T. 1970. The effect of seedless versus seeded fruit development on flower bud formation in pear. *J. Am. Soc. Hort. Sci.* 95: 243 - 248.

Guardiola, J.L. 1988. Factors limiting productivity in Citrus. A physiological approach. *Proc. 6th Int. Citrus Congress.* 1: 381 - 394.

Huet, J. 1973. Floral initiation in pear trees. *Acta Hort*. 34: 193 - 198.

Jackson, J.E. 2003. Biology of apples and pears. Cambridge University Press.

Jackson, D.I. and Looney, N.E. 1999. Use of bioregulators in fruit production. pp.101 - 106. In: Jackson, D.I. and Looney, N.E. (Eds.), Temperate and subtropical fruit production. CAB International. Oxford.

Jonkers, H. 1979. Biennial bearing in apple and pear: a literature survey. *Scientia Hort.* 11: 303 - 317.

Kadam, S.S., Dhumal, A. and Shinde, N.N. 1995. Pear. pp. 183 - 202. In: Salunkhe, D. K. and Kadam, S.S. (Eds.), Handbook of fruit science and technology: production, composition, storage and processing. Dekker. New York.

Knight, J.N. 1982. Regulation of cropping and fruit quality of 'Conference' pear by the use of gibberellic acid and thinning II. The effect of ethephon as a flower thinner when used in conjunction with gibberellic acid application. *J. Hort. Sci*. 57: 61 - 67.

Knight, J.N. 1983. Translocation properties of carbaryl in relation to its use as an apple fruit thinner. *J. Hort. Sci*. 58: 371 - 379.

Knight, J.N. 1986. Fruit thinning with carbaryl. *Acta Hort.* 179: 707 - 708.

Knight, J.N. and Browning, G. 1986. Regulation of 'Conference' pear cropping with gibberellic acid and ethephon or paclobutrazol. *Acta Hort*. 179: 337 - 342.

Leopold**,** A .C. 1958. Auxin uses in the control of flowering and fruiting. *Annu. Rev. Plant Physiol*. 9: 281 - 310.

Lewis, C.E,. Walker, J.R.L. and Lancaster, J.E. 1995. Effect of polysaccharides on colour of anthocyanins. *Food Chem.* 54: 315 - 319.

Li, C.J. and Bangerth, F. 1992. The possible role of cytokinins, ethylene and indoleacetic acid in apical dominance. pp. 431 - 436. In: Karssen, C.M., van Loon L.C. and Vreugdenhil, D. (Eds.), Progress in plant growth regulation. Kluwer. Dordrecht.

Link, H. 2000. Significance of flower and fruit thinning on fruit quality. *Plant Growth Regul*. 31: 17 - 26.

Lombard, P.B. 1967. Bartlett pear thinning. *Proc. Wash. State. Hort. Ass.* 63: 169 - 170.

Lombard, P.B. and Strang, J. 1978. The effects of gibberellin application on return bloom, fruit size and cropping the following year of 'Seckel' pear trees (abstract). *HortScience* 13: 345.

Lombard, P.B. 1982. Pear pollination and fruit set. pp. 91 - 103. In: Zwet, T. van der. and Childers, N.F. (Eds.), The pear. Horticultural Publications 3906 NW. Gainsville, Florida.

Looney, N.E. 1983. Growth regulator usage in apple and pear production. pp. 1 - 26. In: Nickell, L.G. (Ed.), Plant growth regulating chemicals. CRC Press, Boca Raton. Florida.

Looney, N.E. 1993. Improving fruit size, appearance and other aspects of fruit crop 'quality' with plant bioregulant chemicals. *Acta Hort*. 329: 120 - 127.

Lötze, E. and Bergh, O. 2004. Early prediction of harvest fruit size distribution of an apple and pear cultivar. *Scientia Hort*. 101: 281 - 290.

Luckwill, L.C.1970. The control of growth and fruitfulness of apple trees. pp. 237 - 254. In: Luckwill, L.C. and Cutting, C.V. (Eds.), Physiology of tree crops. Academic press. London.

Marais, W. F. 1987. Progress with chemical thinning of 'Bon Chrétien' pears. *Dec. Fruit Gr.* 37: 297 - 298.

Marsal, J., Mata, M., Arbones, A., Del Campo, J., Girona, J. and Lopez, G. 2008. Factors involved in alleviating water stress by partial crop removal in pear trees. *Tree Physiol.* 28: 1375 - 1382.

McArtney, S.J. and Wells, G.H. 1995. Chemical thinning of Asian and European pear with ethephon and NAA. *NZ. J. Crop. Hort. Sci*. 23: 73 - 84.

McFerson, J., Auvil, T., Castillo, F. and Schmidt, T. 2005. Organic chemical bloom thinning of tree fruits. pp. 80 - 81. In: Granatstein, D. and Azarenko, A. (Eds.), Proceedings of the third national organic tree fruit research symposium. Washington State University Tree Fruit Research and Extension Center. Wenatchee, Washington.

Meheriuk, M. and Looney, N. E. 1985. Quality of 'Bartlett' pears thinned chemically and by hand. *HortScience* 20: 949 - 950.

Meland, M. 1998. The effect of hand thinning on yield and return bloom of five pear cultivars in a northern climate. *Acta Hort*. 475: 275 - 282.

Meland, M. and Gjerde, B. 1996a. Thinning apples and pears in a Nordic climate 1. The effect of NAA, ethephon and lime sulphur on fruit set, yield and return bloom of four pear cultivars. *Norw. Jour. Agr. Sci.* 10: 437 - 451.

Meland, M. and Gjerde, B. 1996b. Thinning apples and pears in a Nordic climate II. The effect of NAA, ethephon and lime sulphur on fruit quality of four pear cultivars. *Norw. Jour. Agr. Sci.* 10: 453 - 468.

Moran, R.E. and Southwick, S.M. 2000. Chemical bloom thinning of pome and stone fruit. pp. 223 - 254. In: Basra, A. (Ed.), Plant growth regulators in agriculture and horticulture. The Haworth Press. New York.

Naor, A. 2001. Irrigation and crop load influence fruit size and water relations in field-grown 'Spadona' pear. *J. Am. Soc. Hort. Sci*. 126: 252 - 255.

Negi, N.D. and Sharma, N. 2005. Growth, flowering and cropping response of 'Flemish Beauty' pear to bloom spray of gibberellic acid and benzyladenine. *Acta Hort*. 696: 295 - 298.

Nicotra, A. 1982. Growth regulators in pear production. *Acta Hort*. 124: 131 - 148.

Pharis, R.P. and King, R.W. 1985. Gibberellins and reproductive development in seed plants. *Annu. Rev. Plant Physiol*. 36: 517 - 568.

Reginato, G. and Gonzalez, R. 1998. Survey of rates and timing of NAA sprays as fruit thinner in three pear varieties in Chile. *Acta Hort*. 475: 393 - 403.

Reynolds, L.P. 2004. Reproductive bud development in pears. MScAgric thesis. University of Stellenbosch.

Reynolds, L.P., Jacobs, G. and Theron, K.I. 2004. Reproductive bud development of pears (*Pyrus communis* L.) with emphasis on the bourse shoot. *Acta Hort*. 671: 165 - 170

Roberts, J. A., Elliot, K. A. and Gonzales-Carranza, Z. H. 2002. Abscission, dehiscence and other cell separation processes. *Annu. Rev. Plant Biol*. 53: 131 - 158.

Roitsch, T. and Ehne, R. 2000. Regulation of source/sink relations by cytokinins. *Plant. Growth Regul.* 32: 359 - 367.

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

Schönherr, P., Baur, M. and Uhlig, B.A. 2000. Rates of cuticular penetration of 1-naphthylacetic acid (NAA) as affected by adjuvants, temperature, humidity and water quality. *Plant Growth Regul.* 31: 61–74.

Schröder, M. and Bangerth, F. 2006. The possible ´mode of action´ of thinning bioregulators and its possible contribution to the understanding of ´thinning variability´ in apples. *Acta Hort*. 727: 437 - 444.

Sexton, R. 1997. The role of ethylene and auxin in abscission. *Acta Hort*. 463: 435 - 444.

Shargal, A., Golobovich, S., Flaishman, M.A., Shlizerman, L.A., Stern, R.A., Grafi, G., Lev-Yadun, S. and Yablovich, Z. 2006. Synthetic cytokinins extend the phase of division of parenchyma cells in developing pear (*Pyrus communis* L.) fruits. *J. Hort. Sci. Biotechnol*. 81: 915 - 920.

Stern, R.A and Flaishman, M.A. 2003. Benzyladenine effects on fruit size, fruit thinning and return yield of ‘Spadona’ and ‘Coscia’ pear. *Scientia Hort.* 98: 499 - 504.

Stern, R.A., Shargal, A and Flaishman, M.A. 2002. Effects of the synthetic cytokinin CPPU on fruit size and yield of ‘Spadona’ pear (*Pyrus communis* L.). *Acta Hort*. 596: 797 - 801.

Stern, R.A., Shargal, A and Flaishman, M.A. 2003. Thidiazuron increases fruit size of ‘Spadona’ and ‘Coscia’ pear (*Pyrus communis* L.). *J. Hort. Sci. Biotechnol*. 78: 15 - 55.

Steyn, W.J., Wand, S.J.E., Holcroft, D.M. and Jacobs, G. 2002. Anthocyanins in vegetative tissues: A proposed unified function in photoprotection. *New Phytologist* 155: 349 - 361.

Steyn, W.J., Wand, S.J.E., Holcroft, D.M. and Jacobs, G. 2005. Red colour development and loss in pears. *Acta Hort*. 671: 79 - 85.

Stopar, M., Black, B.L. and Bukovac, M.J. 1997. The effect of NAA and BA on carbon dioxide assimilation by shoot leaves of spur-type 'Delicious' and 'Empire' apple trees. *J. Am. Soc. Hort. Sci.* 122: 837 - 840.

Stopar, M., Gregor, A. and Bati, F. 2000. Apple fruitlet abscission is influenced by assimilate supply. *Acta Hort.* 527: 169 - 176

Stover, E.W. 2000. Relationship of flowering intensity and cropping in fruit species. *HortTech.* 10: 729 - 732.

Stover, E.W. and Greene D.W. 2005. Environmental effects on the performance of foliar applied plant growth regulators. *HortTech.* 15: 214 - 221.

Stover, E.W., Wirth, F. and Robinson, T. 2001. A method for assessing the relationship between cropload and crop value following fruit thinning. *HortScience* 36: 157 - 161.

Taiz, L. and Zeiger, E. 2002. Plant Physiology (3rd Ed). Sinauer Associates. Sunderland, Massachusetts.

Theron, K.I., Le Grange, M., Smit, M., Reynolds, S. and Jacobs, G. 2002. Controlling vigour and colour development in the bi-coloured pear cultivar 'Rosemarie'. *Acta Hort.* 596: 753 - 756.

Tromp, J. 2000. Flower-bud formation in pome fruits as affected by fruit thinning. *Plant Growth Regul*. 31: 27 - 34.

Tromp, J. 2005. Flower bud induction pp. 204 - 215. In: Tromp, J., Webster, A.D. and Wertheim, S.J (Eds.), Fundamentals of temperate zone fruit production. Leiden. Backhuys.

Tukey, R.B. 1981. Growth and development in tree fruits. pp. 1 - 45. In: Tukey, R.B. and Williams, M.W. (Eds.), Tree fruit growth regulators and chemical thinning: The proceedings of the 1981 Pacific Northwest tree fruit short course. Pullmen. Washington.

Turner, J.N. 1973. Gibberellic acid for controlling fruit production of pears. *Acta Hort*. 34: 287 - 297.

Turner, J., Bai, J., Marin, A. and Colonna, A. 2005. Consumer eveluation of pear cultivars in the Pacific Northwest, USA. *Acta Hort*. 671: 355 - 360.

Untiedt, R. and Blanke, M. 2001. Effect of fruit thinning agents on apple tree canopy photosynthesis and dark respiration. *Plant Growth Regul*. 35: 1 - 9.

Vilardell, P., Carbó, J., Casals, M., Bonany, J., Asín, L. and Dalmau, R. 2005. Effect of 6-BA and NAA as thinning agents of 'Conference' pear. *Acta Hort*. 671: 119 - 124.

Wand, S.J.E., Steyn, W.J., Holcroft, D.H., Mdluli, M.J., van den Dool, K. and Jacobs, G. 2005. Use of evaporative cooling to improve 'Rosemarie' and 'Forelle' pear fruit blush colour and quality. *Acta Hort*. 671: 103 - 111.

Webster, A.D. 1993. Tree growth control and fruit thinning: Possible alternatives to the use of plant growth regulators. *Acta Hort.* 347: 149 - 161.

Webster, A.D. 2002a. Current approved thinning strategies for apples and pears and recent thinning research in Europe. *Compact Fruit Tree* 35: 73 - 76.

Webster, A.D. 2002b. Factors influencing the flowering, fruit set and fruit growth of European pears. *Acta Hort*. 596: 699 - 709.

Weibel, F.P., Tamm, L., Wyss, E., Daniel, C., Häseli, A. and Suter, F. 2007. Organic fruit production in Europe: successes in production and marketing in the last decade, perspectives and challenges for the future development. *Acta Hort.* 737: 163 - 172.

Weinbaum, S.A., DeJong, T.M. and Maki, J. 2001. Reassessment of seed influence on return bloom and fruit growth in 'Bartlett' pear. *HortScience.* 36: 295 - 297.

Wells, D.J., Wells, C. and Seavert, C.F. 1998. The economics of hand-thinning 'd'Anjou' pears in the hood river valley of Oregon, USA. *Acta Hort*. 475: 405 - 412.

Wertheim, S.J. 1973. Chemical control of flower and fruit abscission in apple and pear. *Acta Hort*. 34: 321 - 331.

Wertheim, S.J. 1990. De Peer. Proefstation voor de Fruitteetlt, Wilhemibnadorp. pp 88 - 94.

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

Wertheim, S.J. 2000. Developments in the chemical thinning of apple and pear. *Plant Growth Regul.* 31: 85 - 100.

Wertheim, S.J. and Webster, A.D. 2005. Manipulation of growth and development by plant bioregulators pp. 267 - 288. In: Tromp, J., Webster, A.D. and Wertheim, S.J (Eds.), Fundamentals of temperate zone fruit production. Leiden. Backhuys.

Wertheim, S.J., Wagenmakers, P.S., Bootsma, J.H. and Groot, M.J. 2001. Orchard systems for apple and pear: conditions for success. *Acta Hort*. 557: 209 - 227.

Westwood, M.N. 1993. Temperate-zone pomology: physiology and culture (3rd Ed.). Timber Press. Portland, Oregon. pp. 210 - 215.

Williams, M.W. 1973. Chemical thinning and guide for size thinning 'Bartlett' pears. *Proc. Wash. State Hort. Ass.* 69: 167 - 170.

Williams, M.W. 1977. Fruit set of 'Anjou' and growth of 'Bartlett' pears. *Acta Hort*. 69: 257 - 260.

Williams, M.W. 1979. Chemical thinning of apples. pp. 270 - 300. In: Janick, J. (Ed.), Hort. Rev 6. Wiley J. and Sons Publishers. New Jersey.

Williams, M.W. 1981. Combinations of bio-regulants on apple trees. pp. 213 - 218. In: Tukey, R.B. and Williams, M.W (Eds.), Tree fruit growth regulators and chemical thinning: The proceedings of the 1981 Pacific Northwest tree fruit short course. Pullmen. Washington

Williams, M.W. 1994. Factors influencing chemical thinning and update on new chemical thinning agents. *Compact Fruit Tree* 27: 115 - 122.

Williams, M.W. and Edgerton, L.J. 1981. Fruit thinning of apples and pears with chemicals. USDA Agr. Bul. 289.

Wolstenholme, B.N. 1990. Resource allocation and vegetative - reproductive competition: opportunities for manipulation in evergreen fruit trees. *Acta Hort*. 275: 451 - 460.

Yang, S.F. 1980. Regulation of ethylene biosynthesis. *HortScience* 15: 115 - 122.

Yuan, R. and Greene, D.W. 2000. Benzyladenine as chemical thinner for 'McIntosh' apples. I. Fruit thinning effects and associated relationships with photosynthesis, assimilate translocation, and non-structural carbohydrates. *J. Amer. Soc. Hort. Sci.* 125: 169 - 176.

CHAPTER 2

Evaluation of 6-benzyladenine (BA) and naphthylacetamide (NAD) as post-bloom thinning compounds for 'Early Bon Chrétien' pear

Abstract

Pear trees often set an excessive amount of fruit and therefore require fruit thinning early in the season to improve fruit size at harvest and return bloom. Experiments were conducted in the 2004/5 and 2006/7 seasons in the Western Cape, South Africa to evaluate the efficacy of 6-benzyladenine (BA) and naphthylacetamide (NAD) on fruit set, fruit size at harvest and return bloom of 'Early Bon Chrétien' pear. The treatments, BA (50, 100 and 150 $mg.l^{-1}$) and NAD (30 and 40 $mg.l^{-1}$) were compared to unsprayed controls. BA proved to be the most efficient thinner of 'Early Bon Chrétien' when used at rates of 100 or 150 $mg.l^{-1}$. Fruit set was significantly reduced and the number of large fruit increased compared to the control. BA effects were generally additive, fruit set and yield decreased, while fruit size increased with an increase in rate. The 150 $mg.l^{-1}$ BA rate was the most effective treatment. 100 and 150 $mg.l^{-1}$ BA significantly improved return bloom compared to 30 and 40 $mg.l^{-1}$ NAD and the control.

Keywords: benzyladenine, fruit set, fruit size, fruit weight, naphthylacetamide.

Introduction

European pear cultivars often set an excessive number of fruit, which then results in small fruit size at harvest and a reduction in return bloom, leading to an undesirable alternate bearing pattern. Cultivars which are harvested early in the season, have higher bloom densities and heavier fruit set the next spring (Tukey, 1981). This is probably due to the effect of early harvesting on tree reserves, flower bud development and flower quality. These "early" cultivars have fewer post-bloom days to partition assimilates to the developing fruitlets, a basic requirement for optimum fruit growth (Marais, 1987; Webster, 2002a). The 'Early Bon Chrétien' pear is a mutation of 'Williams Bon Chrétien', which ripens approximately two weeks earlier. It is believed to have a lower chill requirement and therefore also blooms

approximately one week earlier than 'Williams Bon Chrétien' (Theron, pers. comm.). It is an important pear cultivar, as it is produced for fresh export and processing in South Africa. The export market requires that the fruit be harvested firm, thus harvesting is done earlier and even fewer days after full bloom (d.a.f.b.) (Marais, 1987). It flowers profusely and normally sets heavy crops. In order to attain the fruit sizes that comply with export standards, crop load must be adjusted/reduced to optimum levels as early as possible (Marais, 1987).

Fruit thinning is conventionally done by hand, however, it requires high labour input to achieve this within the optimum time span and is expensive (Williams, 1994; Dennis, 2000; Webster, 2002a). Therefore, various chemical thinning agents have been evaluated for their ability to reduce crop load, increase fruit size and return bloom on European pear cultivars. The post bloom thinning agents, 6-benzyladenine (BA) and naphthylacetamide (NAD) have produced the most promising thinning results in fairly recent trials on European pear cultivars (Wertheim, 2000; Webster 2002a; Dussi *et al.,* 2008).

BA is a synthetic cytokinin which increases fruit size by stimulating cell division in addition to reducing crop load (Greene, 1993; Bubán, 2000; Wertheim, 2000; Webster, 2002a). According to Yuan and Greene (2000), the induction of fruitlet abscission by BA is a result of a temporary reduction in photosynthesis and an increase in dark respiration, which leads to limited carbohydrate supply to the fruitlets. However, other researchers are of the opinion that BA does not affect leaf assimilation (Stopar *et al.,* 1997; Wertheim, 2000). The current opinion is that BA induces fruitlet abscission by stimulating the growth of lateral side shoots, such as the bourse shoot (Faust, 1989; Elfving and Cline, 1993; Williams, 1994). IAA transport out of all these newly released lateral buds may correlatively inhibit IAA transport from fruit leading to the abscission of some of them (Bangerth, 2000).

NAD is a synthetic auxin which reduces crop load, improves fruit size and return bloom (Wertheim, 2000; Bonghi *et al*., 2002; Webster, 2002a). It has been suggested that NAD induces fruit abscission by temporarily disrupting the efflux of diffusible

auxin (IAA) from weaker, lateral fruitlets, which restricts their assimilate supply (Bangerth, 2000; Webster, 2002a; b). It has also been suggested that NAD causes a temporary reduction in photosynthesis and the movement of assimilates to the fruits by reducing the conductance of CO_2 in the mesophyll (Webster, 2002b; Jackson, 2003), resulting in the abscission of lateral fruitlets due to nutrient starvation (Bangerth, 2000; 2004). Leaf injury and inhibition of fruit growth has been reported when NAD is applied at rates higher than 20 $mg.l^{-1}$ (Lombard, 1967; Meheriuk and Looney, 1985; Wertheim, 2000; Bonghi *et al*., 2002). Late applications may slow down fruit growth leading to a reduction in fruit size at harvest (Wertheim, 2000).

The experiments described in this paper were designed to evaluate the effects of BA and NAD on fruit set, fruit size and quality at harvest and return bloom of 'Early Bon Chrétien' pear.

Materials and Methods

Plant Material

The trials were conducted on two farms in the Western Cape, South Africa, within the Mediterranean climatic region. La Plaisante Estate, situated in the Wolseley area (33°25′S, 19°12′E) and Buchuland situated in the Ceres area (33°15′ S, 19°15′ E). Trials were conducted in (i) the 2004/2005 season at La Plaisante Estate and (ii) the 2006/2007 season at La Plaisante Estate and Buchuland. Relevant orchard details for each site are presented in Table 1. Trees were selected for uniformity of size and blossom density and harvesting of fruit was undertaken on the same days as the commercial harvest on each farm.

Treatments and experimental design

MaxCel ™, containing 1.9 % (w/w) of 6-BA, and Golden Thin®, containing 10 % (w/w) of NAD were applied at 8 to 12 mm fruit diameter in the 2004/5 season. In the 2006/7 season, NAD was applied 2 to 5 d.a.f.b. In all trials, both post-bloom thinning agents were applied at low volume using a motorised knapsack sprayer at 1 000 $L.ha^{-1}$. Surfactants were not added to the spray solution. In the 2004/2005 season, three rates of BA, 50, 100 and 150 $mg.l^{-1}$ and one rate of NAD, 30 $mg.l^{-1}$, were applied and compared to an unsprayed control. In the 2006/2007 season, two rates of BA, 100 and 150 $mg.l^{-1}$, and one rate of NAD, 40 $mg.l^{-1}$, where applied and compared to an unsprayed control. Application dates and weather conditions at spraying time in each trial are presented in Table 2. The experimental designs for all trials were randomised complete block designs with 10 single-tree plot replications of either four or five treatments. All treatments were hand thinned after the natural fruit drop period (see Table 1) to improve fruit distribution within the canopy.

Data collected

At bloom, two representative branches were tagged in the lower sector of the trees and the number of flower clusters on these branches was recorded. Trunk circumference was measured approximately 20 cm above the graft union. After the natural fruit drop period (Table 1), fruit set per cluster on the tagged branches was recorded. The number of fruitlets thinned by hand from the whole tree was also recorded. At harvest, fruit from each tree were weighed to determine the yield for each treatment. A randomly selected sample of 25 fruit per tree was collected and analysed for the following fruit quality parameters; fruit diameter, length and weight, number of developed seeds and the number of seeds with aborted embryos, solid and retiform russet and calyx-end ribbing. Calyx-end ribbing was determined by visual observation (see Plate 1). Solid russet was evaluated on a scale of 1 to 8 using the Deciduous Fruit Board solid russet chart number P17 (1 = most solid russet; 8 = least solid russet). Retiform russet was evaluated on a scale of 1 to 8 using the Deciduous Fruit Board retiform russet chart number P8 (1 = most retiform russet; 8 = least

retiform russet). The remainder of the fruit were sample graded, and pack-out percentage was determined (average 2 bulk bins per treatment). Grading data were expressed as percentage of fruit larger or smaller than 150 grams in 2004/5 and 140 grams in 2006/7. Return bloom was monitored during the following season on branches tagged for fruit set counts, by counting the vegetative and reproductive buds that sprouted on these two tagged branches. The reproductive buds were expressed as a percentage of the total number of buds sprouted.

Statistical analysis

The General Linear Models (GLM) procedure of the Statistical Analysis System (SAS® 9.1.2, SAS Institute Inc, 2004, Cary, NC) was used to analyse the data. Fruit set and number of fruitlets thinned by hand were used as covariates for the analysis of their effects on fruit diameter, length and weight at harvest and on return bloom.

Results

Fruit set and the number of fruits thinned by hand

BA and NAD sprays significantly reduced fruit set on the two tagged branches and reduced (not always significantly) the number of fruitlets that had to be thinned by hand in two out of the three trials (Table 3). At the La Plaisante site in 2004/5, fruit set on the two tagged branches was reduced by all chemical treatments (Table 3). All BA rates significantly reduced fruit set, the highest BA rate of 150 $mg.l^{-1}$ reduced fruit set by approximately 60 % compared to the control. The lower rates of 50 and 100 $mg.l^{-1}$ reduced fruit set by approximately 25 % of that of the control (Table 3). All BA rates reduced the number of fruitlets that had to be thinned by hand relative to the control. 100 and 150 $mg.l^{-1}$ BA significantly reduced the number of fruitlets that had to be thinned by hand, by ± 42 and ± 45 % of the control, respectively (Table 3). The lowest BA rate, 50 $mg.l^{-1}$ reduced the number of fruitlets that had to be thinned by hand, by ± 26 % of the control, however, this was not statistically significant (Table

3). 30 mg.l^{-1} NAD significantly reduced fruit set by approximately 41 % of the control. This rate also reduced the average number of fruitlets that had to be thinned by hand, by ± 33 % of the control, however, this was not statistically significant (Table 3).

At the Buchuland site in 2006/7, differences in fruit set on the two tagged branches between the chemical thinning treatments and the control and between the BA and NAD treatments were statistically significant (Table 3). The two BA rates applied, 100 and 150 mg.l^{-1}, significantly reduced fruit set by ± 42 and ± 51 % of the control, respectively. These two rates of BA significantly reduced the number of fruitlets that had to be thinned by hand relative to the control, by ± 26 and ± 42 % respectively (Table 3). NAD at 40 mg.l^{-1} significantly reduced fruit set by approximately 20 %. This rate also reduced the number of fruitlets that had to be thinned by hand by approximately 13 % relative to the control, however, this was not statistically significant (Table 3).

At the La Plaisante site in 2006/7, BA and NAD did not significantly affect fruit set or the number of fruitlets that had to be thinned by hand compared to the control. The two BA rates, 100 and 150 mg.l^{-1}, reduced fruit set by ± 26 and ± 20 % respectively, however, none of the fruit set reductions were statistically significant when compared to the set of the control trees. These rates reduced the number of fruitlets that had to be thinned by hand, by ± 33 and ± 11 % of the control respectively, however, these reductions were also not statistically significant (Table 3). NAD at 40 mg.l^{-1} increased fruit set by approximately 16 %, and the number of fruitlets that had to be thinned by hand, by approximately 12 % relative to the control, however, these increases were not statistically significant (Table 3). NAD increased fruit set significantly relative to the two BA rates (Table 3).

Yield and fruit size

At the La Plaisante site in 2004/5, BA and NAD sprays had a statistically significant

(p= 0.0006) effect on yield (Table 4), with only the highest rate of BA and the NAD application reducing yield efficiency significantly by ± 28 and ± 29 % respectively. No statistically significant differences were found in yield efficiency at the Buchuland and La Plaisante sites in the 2006/7 season (Table 4).

No statistically significant differences were found between the BA and NAD sprays and control on fruit diameter at any of the sites in any season (Table 5; 6; 7). At the La Plaisante site in 2004/5, both BA and NAD significantly increased fruit length. BA at 100 and 150 $mg.l^{-1}$ significantly increased fruit weight by ± 5 and ± 7 % of the control respectively (Table 5). NAD at 30 $mg.l^{-1}$ significantly increased fruit weight by approximately 6 % relative to the control. Using the number of fruits thinned by hand as a covariate made the treatment effects become non-significant at the La Plaisante site in 2004/5 (Table 5).

At the Buchuland and La Plaisante sites in the 2006/7 season, no statistically significant differences in fruit size were found between the BA and NAD sprays and the unsprayed control (Table 6; 7). Although the number of fruits thinned by hand was a significant covariate for fruit length at these sites in the 2006/7 season it did not make the treatment effect become significant (Table 6; 7).

The BA and NAD treatments resulted in a discernable shift in fruit grade distribution (g/fruit) from lower to higher categories relative to the control (Fig. 4; 5). The fruit grading distribution data were not statistically analysed due to it being a pooled sample from the different replications. At the La Plaisante site in 2004/5, all treatments increased the percentage of fruits larger than 150 g relative to the control (Fig. 1). The 150 $mg.l^{-1}$ BA rate was the most effective treatment, while 30 $mg.l^{-1}$ NAD was more effective than the lower BA rates, 50 and 100 $mg.l^{-1}$ (Fig. 4).

At the La Plaisante site in 2006/7, the BA and NAD treatments reduced the percentage of fruit in the lower fruit size grades (smaller than 140 grams) relative to the control (Fig. 5). BA at 100 and 150 $mg.l^{-1}$ resulted in more fruit larger than 140

grams compared to 40 mg.l^{-1} NAD, with the 150 mg.l^{-1} BA rate being the most effective treatment (Fig. 5). No discernable shift in fruit size distribution was observed with 100 and 150 mg.l^{-1} BA and 40 mg.l^{-1} NAD, relative to the control at the Buchuland site in 2006/7 (Fig. 6).

Fruit quality and seed abortion

No statistically significant differences were found in solid russet and percentage fruit with calyx-end ribbing at any of the sites in any season (Table 8). Retiform russet was not affected by BA and NAD sprays at the La Plaisante site in the 2004/5 season or at the Buchuland site in the 2006/7 season (Table 8). BA at 100 mg.l^{-1} and 40 mg.l^{-1} NAD significantly reduced retiform russet at the La Plaisante site in the 2006/7 season by ± 42 and ± 54 % of the control respectively (Table 8). BA at 150 mg.l^{-1} significantly increased the number of well-developed seeds while significantly reducing seed abortion relative to the control at the La Plaisante site in the 2004/5 season and at the Buchuland site in the 2006/7 season (Table 9). However, these increases were biologically probably insignificant (Table 9). BA and NAD sprays did not significantly affect the number of well-developed or aborted seeds at the La Plaisante site in the 2006/7 season (Table 9).

Return bloom

BA significantly increased percentage return bloom on two tagged branches in two out of the three trials (Table 10; 11). At the La Plaisante site in the 2004/5 season, all BA rates applied the previous season significantly increased return bloom relative to the unsprayed control. 50 and 100 mg.l^{-1} BA increased return bloom by ± 105 %, while the highest rate, 150 mg.l^{-1} increased return bloom by ± 140 % of the control (Table 10). NAD at 30 mg.l^{-1} increased return bloom by ± 54 %, however this increase was not statistically significant (Table 10). Fruit set and number of fruits thinned by hand were significant covariates for return bloom, but only slightly reduced the significance level of the treatments (Table 10).

For the 2006/7 season trials, the 100 and 150 mg.l^{-1} BA rates increased return bloom, whereas the 40 mg.l^{-1} NAD did not affect return bloom relative to the control. At the two sites in the 2006/7 season, statistically significant differences between BA and NAD treatments in return bloom were obtained (Table 11). A statistically significant increase in return bloom of approximately 30 % of the control was obtained with the two BA rates, 100 and 150 mg.l^{-1} at the Buchuland site (Table 11). At the La Plaisante site, 100 and 150 mg.l^{-1} BA increased return bloom by approximately 16 % of the control, however, these increases were not statistically significant (Table 11). A ± 12 % reduction in return bloom, relative to the control, was obtained with 40 mg.l^{-1} NAD, however, this was also not statistically significant (Table 11). Using the fruit set and number of fruits thinned by hand as covariates, the treatment effect was slightly less significant at Buchuland and became non-significant at the La Plaisante site in 2006/7 (Table 11).

Discussion

Fruit set and the number of fruits thinned by hand

BA at 100 or 150 mg.l^{-1} reduced fruit set and subsequently, the number of fruits that had to be removed by hand thinning. The 50 mg.l^{-1} BA rate was omitted from the treatments in the 2006/7 season because it was found to be ineffective for reducing the number of fruit that had to be thinned by hand and increasing fruit weight in the 2004/5 season. BA at 150 and 200 mg.l^{-1} significantly reduced fruit set in two out of three trials (Table 3). The 150 mg.l^{-1} treatment tended to perform best. This is in agreement with the results obtained in previous pear trials where it was found that in 'Packham's Triumph' (Bound and Mitchell, 2002) and 'Clara Frijs' (Bertelsen, 2002), fruit set was effectively reduced by BA at 100 to 150 mg.l^{-1}. In recent trials conducted in Argentina by Dussi *et al.* (2008), BA effectively reduced crop load and the number of fruits that had to be thinned by hand on 'Williams Bon Chrétien' pear trees using rates exceeding 150 mg.l^{-1}. A higher rate of BA, 200 mg.l^{-1} was required to reduce fruit set on 'Conference', as 100 mg.l^{-1} was ineffective (Wertheim, 2000: Vilardell *et al.,* 2005).

The reduction in fruit set was higher at Buchuland as compared to that at La Plaisante in the same season, 2006/7 (Table 3). Bloom density at Buchuland was observed to be higher than that at La Plaisante, proving that chemical thinning agents are more effective under conditions of high blossom density (Williams, 1994; Webster, 2002a). Temperature before and after application influence the efficacy of thinning compounds (Wertheim, 2000). According to Bubán and Lakatos (2000), BA is effective when there is an increase in mean daily temperatures 5 to 10 days after application. A decrease in mean daily temperatures during the same period after application reduces the efficacy of BA (Bubán, 2000; Bubán and Lakatos, 2000). An increase in mean daily temperatures was observed at the La Plaisante site in 2004 (Fig. 1) and at the Buchuland site in 2006 (Fig. 2) 5 days after the BA application date. A decrease in mean daily temperatures was observed at the La Plaisante site in 2006 (Fig. 3) 5 days after the BA application date. This could have contributed to the positive thinning results obtained with BA at the La Plaisante site in the 2004/5 season and at the Buchuland site in the 2006/7 season and the negative results obtained with BA at the La Plaisante site in the 2006/7 season (Table 3).

In South Africa, the registered rate of Golden Thin ® (NAD) on apples is 70 $mg.l^{-1}$. NAD at 30 and 40 $mg.l^{-1}$ significantly reduced fruit set, however, it did not significantly reduce the number of fruits that had to be thinned by hand. This is probably because NAD thinned within the cluster, reducing the proportion of clusters that have more than on fruit. According to Knight (1986), thinning within the cluster is more beneficial to both fruit size and return bloom than simple whole cluster removal. At rates of 15 to 20 $mg.l^{-1}$, NAD reduced fruit set on 'Coscia' (Stern and Flaishman, 2003), 'Conference' and 'Rosada' pear (Bonghi *et al.*, 2002). NAD at the rate used in our trials was generally less effective in reducing fruit set than BA. It even increased fruit set and the number of fruits that had to be thinned by hand at the La Plaisante site in the 2006/7 season. This is probably because of weather conditions prior to application, as spraying NAD after cool and moist weather may increase fruit set (Wertheim, 1997; 2000). Mean daily temperatures prior to NAD application were relatively low (less than 15 °C), whilst relative humidity was comparatively high (fluctuating between 60 and 80 %) (Fig. 3). Although the recommended time for applying NAD is 2 to 5 d.a.f.b. (Wertheim, 2000), Bukovac (1964) found NAD more

effective in reducing fruit set on 'Bon Chrétien' when applied ± 14 days after petal fall than at petal fall. At the La Plaisante site, NAD was applied 13 d.a.f.b. in the 2004/5 and 4 d.a.f.b. in the 2006/7 season (Table 1; 2). This possibly explains why NAD at this site effectively reduced fruit set in the 2004/5 season and failed to do so in the 2006/7 season (Table 3).

Yield and fruit size

The BA and NAD treatments did not significantly affect yield efficiency apart from the one trial at La Plaisante in 2004/5 season where 150 $mg.l^{-1}$ BA and 30 $mg.l^{-1}$ NAD significantly reduced yield efficiency. The BA and NAD (not at Buchuland) treatments increased fruit diameter, however these increases were not significant relative to the control (Table 5; 6; 7). The effect of BA on fruit size (diameter and weight) was largely additive, fruit size increased with increasing rate. Although the BA and NAD sprays generally increased fruit weight in our trials, these increases were only significant at the La Plaisante site in the 2004/5 season (Table 5). In this trial, 100 and 150 $mg.l^{-1}$ BA as well as 30 $mg.l^{-1}$ NAD significantly increased fruit weight. The number of fruits thinned by hand as a covariate was significant for fruit weight at the La Plaisante site in 2004/5 (Table 5) with the treatment effect becoming less significant. This implies that the thinning effect was partially responsible for the increase observed in fruit weight. Therefore, the increase in fruit size can be attributed mainly to a direct effect of BA. BA prolongs and/or increases the rate of mitotic cell division in the cortex of developing fruitlets (Shargal *et al.,* 2006). This increase in cell division improves sink strength. An increase in assimilate influx to BA-treated organs has been reported, with treatments at earlier growth stages being more effective in promoting assimilate efflux from leaves adjacent to the application sites (Bubán, 2000).

Since fruit size distribution per tree corresponds to a normal distribution curve, every effective thinning treatment shifts the curve from the lower size categories to the higher ones (Link, 2000). Generally fruit required by the export market is 140 - 150 g/fruit or larger (Jones *et al.,* 2000). However, this varies with the target market,

American and Asian consumers prefer bigger fruit, whilst European consumers prefer smaller fruit (Theron, pers. comm; Wertheim, 2000). Surprisingly, there was no discernable shift in fruit size distribution relative to the control at the Buchuland site in the 2006/7 season (Fig. 6). In this trial, BA and NAD produced the highest reduction in fruit set. However, over 80 % of the fruits from each treatment were in the >140 grams category. Similar results were reported by Wertheim (2000) on 'Conference' pear, where 200 $mg.l^{-1}$ reduced fruit set without affecting fruit size or return bloom as both were already at acceptable levels. In two out of three trials, 100 and 150 $mg.l^{-1}$ BA resulted in a higher percentage of larger fruits and a lower percentage of smaller fruits, relative to the hand thinned control (Fig. 4; 5). The highest BA rate, 150 $mg.l^{-1}$ was the most effective treatment. Similar results with BA were reported on 'Clara Frijs' (Bertelsen, 2002), 'Spadona', 'Coscia' (Stern and Flaishman, 2003) and 'Williams Bon Chrétien' pear (Dussi *et al.,* 2008). BA was generally more effective than NAD. NAD at 30 and 40 $mg.l^{-1}$ resulted in a higher percentage of larger fruits and a lower percentage of smaller fruits, relative to the unsprayed control (Fig. 4; 5). NAD has been found to increase fruit size on 'Bon Chrétien', 'Conference' and 'Rosada' pear (Marais, 1987; Bonghi *et al.,* 2002).

Fruit quality and seed abortion

Chemical thinning is performed during the most sensitive phase of fruit development for the induction of russet. It is therefore expected that thinning compounds might influence the incidence of fruit russet (Link, 2000). According to Greene (1993), BA may enhance severe fruit skin russet on apples when used at rates exceeding 100 $mg.l^{-1}$. BA at 50, 100 and 150 $mg.l^{-1}$ generally had no effect on solid and retiform russet and calyx end ribbing on pear (Table 8), thus unlike with apples (Greene, 1993), BA does not seem to induce russet on 'Early Bon Chrétien' pears. On pear, BA is milder than other post-bloom thinning agents such as carbaryl which is known to promote russet (Williams, 1994; Link, 2000; Wertheim, 2000).

All BA treatments increased the number of well developed seeds, however, only for the highest rate (150 $mg.l^{-1}$) it was significant (Table 9). Seed numbers were very

low, ± 1 well-developed seed per fruit (Table 9), therefore this slight increase, though significant, would probably have had little biological effect. BA at the same rate had no significant effect on the number of well developed seeds of 'Bon Chrétien' (Dussi *et al.,* 2008), 'Spadona' and 'Coscia' pears (Stern and Flaishman, 2003). The lower BA rates of 50 and 100 mg.l^{-1} did not significantly affect seed number (Table 9). BA generally did not affect seed numbers, therefore the increase in size was probably not related to a change in seed numbers, but can be attributed to the reduction in crop load (Table 3) and the direct effect of BA as mentioned before (Stern and Flaishman, 2003).

According to Meheriuk and Looney (1985), NAD does not have any serious detrimental effects on 'Bon Chrétien' pear quality at harvest or after storage. In our trial, NAD did not promote russet and calyx end ribbing. At a rate of 40 mg.l^{-1}, NAD significantly reduced retiform russet by 46 % at La Plaisante in the 2006/7 season (Table 8). This is probably because NAD has a smoothing effect on fruit skin quality (Link, 2000). Seed numbers were not significantly affected by 30 or 40 mg.l^{-1} NAD.

Return bloom

BA at 50 to 150 mg.l^{-1} significantly increased return bloom, which was also observed on 'Clara Frijs' pear trees (Bertelsen, 2002). The increase in return bloom could probably be attributed to the thinning effect and the removal of fruitlets before embryo development, as seeds are known to produce phytohormones, particularly gibberellins, which inhibit floral induction (Tromp, 2000; Webster, 2002a;b). Secondly, to the direct effect of BA as cytokinins are known to promote flower bud formation (Wertheim, 1990; Bubán, 2000).

Analysis of covariance with fruit set suggested that the increase in return bloom associated with BA was a direct effect rather than a secondary effect from thinning (Table 10; 11). This is because, the inclusion of fruit set as a covariate in the analysis of the return bloom data did not appreciably affect the treatment significance level in

two out of the three trials (Table 10; 11). Therefore, both fruit set reduction and the direct effect of BA have an important effect on flower bud formation. High levels of cytokinin during flower induction are known to increase the number of reproductive buds induced whilst high levels of cytokinins during the time of flower initiation and differentiation will improve flower quality (Wertheim, 1990; Reynolds, 2004). However, there is no evidence that cytokinins can replace the florally inductive stimulus (Wilkie *et al.,* 2008).

It is widely accepted that the presence of a large number of fruits 7 to 14 d.a.f.b. is antagonistic to flower bud formation (Tromp, 2000). NAD at 30 $mg.l^{-1}$ improved return bloom by about 50 % at the La Plaisante site in the 2004/5 season, however, this was not statistically significant (Table 10). The stimulation of return bloom by NAD at this rate is probably due to an early reduction in crop load (Table 3). At the La Plaisante site in the 2006/7 season, 40 $mg.l^{-1}$ NAD slightly reduced return bloom (Table 11). This is probably because in this trial NAD increased fruit set by approximately 16 % (Table 3). Although 40 $mg.l^{-1}$ NAD effectively reduced fruit set early, return bloom was not affected at the Buchuland site in the 2006/7 season. Therefore, this rate of NAD is probably antagonistic to flower bud formation. Higher rates of NAD have reportedly caused considerable leaf injury on 'Bon Chrétien' (Lombard, 1967), 'Rosada' and 'Conference' (Wertheim, 2000; Bonghi *et al.,* 2002). This reduces the amount of assimilates produced, that will be available to the developing flower buds, which compete with fruitlets and vegetative shoots for assimilates, resulting in possible abortion of developing flower buds. Auxins applied during the early stages of fruit growth tend to inhibit flower induction directly (Westwood, 1993), by enhancing the effect of gibberellins (Bubán, 1996).

Conclusion

BA is a promising post-bloom thinning agent for 'Early Bon Chrétien', as it reduces fruit set relatively early, thus reducing labour costs whilst improving fruit size, fruit size distribution and return bloom. The efficacy of this chemical thinning agent increased with rate. An application of 150 $mg.l^{-1}$ BA is recommended under

conditions less favourable to chemical thinning such as, when trees are in good vigour with terminal growth with no mineral deficiencies and when insect pollination occurs in cross pollinated orchards (Williams, 1994). Under conditions more favourable for chemical thinning such as, low nitrogen levels with inadequate moisture and self pollinated or poorly pollinated trees (Williams, 1994), the lower rate of 100 $mg.l^{-1}$ is recommended. NAD is also an effective post bloom thinning agent, as it reduced fruit set and improved fruit size and fruit size distribution. However, its inability to improve on return bloom is undesirable. In our trials, 100 and 150 $mg.l^{-1}$ BA proved to be a more effective post-bloom chemical thinning agent than 30 and 40 $mg.l^{-1}$ NAD. The reduction in yield efficiency by the thinning agents may be compensated for by the higher value of the remaining fruit (Stern and Flaishman, 2003). Further trials are needed to evaluate the mode of action of BA, the effect of BA when applied at different stages of fruit growth and to do an economical study on the benefits of using BA as chemical thinning agent rather than just using hand thinning.

Literature cited

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

Bangerth, F. 2004. Internal regulation of fruit growth and abscission. *Acta Hort.* 636: 235 - 248.

Bertelsen, M.G. 2002. Benzyladenine and other thinning agents for pear cv. Clara Frijs. *J. Amer. Pomol. Soc.* 56: 149 - 155.

Bonghi, C., Poja, M. and Ramina, A. 2002. Ethephon, NAA and NAD as chemical thinners of pear fruitlets. *Acta Hort.* 596: 717 - 722.

Bound, S.A. and Mitchell, L. 2002. A new post-bloom thinning agent for 'Packham's Triumph' pear. *Acta Hort.* 596: 793 - 796.

Bubán, T. 1996. Flower development and formation of sexual organs. pp. 3 - 54. In: Nyéki J. and Soltész, M. (Eds.), Floral biology of temperate zone fruit trees and small fruits. Akadémiai Kiadó. Budapest.

Bubán, T. 2000. The use of benzyladenine in orchard fruit growing: a mini review. *Plant Growth Regul.* 32: 381 - 390.

Bubán, T. and Lakatos, T. 2000. Contributions to the efficacy of benzyladenine as a fruit thinning agent for apple cultivars. *Acta Hort*. 514: 59 - 67.

Bukovac, M. 1964. Chemical thinning of pears with naphthylacetamide. *Annual Rep. Mich. State Hort. Soc*. 94: 59 - 63.

Dennis, F.G. 2000. The history of fruit thinning. *Plant Growth Regul.* 31: 1 - 16.

Dussi, M.C., Giardina G., Reeb, P. and Gastiazoro, J. 2008. Thinning programs in pears cv. Williams. *Acta Hort* (*accepted for publication*).

Elfving, D.C. and Cline, R.A. 1993. Cytokinin and ethephon affect crop load, shoot growth, and nutrient concentrate of 'Empire' apple trees. *HortScience* 28: 1011 - 1014.

Faust, M. 1989. Physiology of temperate zone fruit trees. Wiley. New York. pp. 169 - 234.

Greene, D.W. 1993. A review of the use of benzyladenine (BA) as a chemical thinner for apples. *Acta Hort.* 329: 231 - 236.

Jackson, J.E. 2003. Biology of apples and pears. Cambridge University Press.

Jones, K.M., Bound, S.A., Oakford, M.J. and Gillard, P. 2000. Modelling thinning of pome fruits. *Plant Growth Regul.* 31: 75 - 84.

Knight, J.N. 1986. Fruit thinning with carbaryl. *Acta Hort.* 179: 707 - 708.

Link, H. 2000. Significance of flower and fruit thinning on fruit quality. *Plant Growth Regul.* 31: 17 - 26.

Lombard, P. B. 1967. Bartlett pear thinning. *Proc. Wash. State. Hort. Ass.* 63: 167 - 170.

Marais, W. F. 1987. Progress with chemical thinning of 'Bon Chrétien' pears. *Dec. Fruit Gr.* 37: 297 - 298.

Meheriuk, M. and Looney, N. E. 1985. Quality of 'Bartlett' pears thinned chemically and by hand. *HortScience* 20: 949 - 950.

Reynolds, L.P. 2004. Reproductive bud development in pears. MScAgric thesis. University of Stellenbosch.

Shargal, A., Golobovich, S., Flaishman, M. A., Shlizerman, L. A., Stern, R. A., Grafi, G., Lev-Yadun, S. and Yablovich, Z. 2006. Synthetic cytokinins extend the phase of division of parenchyma cells in developing pear (*Pyrus communis* L.) fruits. *J. Hort. Sci. Biotechnol.* 81: 915 - 920.

Stern, R.A and Flaishman, M.A. 2003. Benzyladenine effects on fruit size, fruit thinning and return yield of 'Spadona' and 'Coscia' pear. *Scientia Hort.* 98: 499 - 504.

Stopar, M., Black, B.L. and Bukovac, M.J. 1997. The effect of NAA and BA on carbon dioxide assimilation by shoot leaves of spur-type 'Delicious' and 'Empire' apple trees. *J. Am. Soc. Hort. Sci.* 122: 837 - 840.

Tromp, J. 2000. Flower-bud formation in pome fruits as affected by fruit thinning. *Plant Growth Regul*. 31: 27 - 34.

Tukey, R.B. 1981. Growth and development in tree fruits. pp. 1 - 45. In: Tukey, R.B. and Williams, M.W. (Eds.), Tree fruit growth regulators and chemical thinning: The proceedings of the 1981 Pacific Northwest tree fruit short course. Pullmen. Washington.

Vilardell, P., Carbó, J., Casals, M., Bonany, J., Asín, L and Dalmau, R. 2005. Effect of 6-BA and NAA as thinning agents of 'Conference' pear. *Acta Hort.* 671: 119 - 124.

Webster, A.D. 2002a. Current approved thinning strategies for apples and pears and recent thinning research in Europe. *Compact Fruit Tree* 35: 73 - 76.

Webster, A.D. 2002b. Factors influencing the flower, fruit set and fruit growth of European pears. *Acta Hort.* 596: 699 - 709.

Wertheim, S.J. 1990. De Peer. Proefstation voor de Fruitteetlt, Wilheminadorp. pp 88 -94.

Wertheim, S.J. 2000. Developments in the chemical thinning of apple and pear. *Plant Growth Regul.* 31: 85 - 100.

Westwood, M.N. 1993. Temperate-Zone Pomology: Physiology and Culture (3rd ed.), Timber Press, Portland, Oregon. pp. 210 - 215.

Wilkie, J.D., Sedgley, M. and Olesen, T. 2008. Regulation of floral initiation in horticultural trees. *J. Exp.Bot.* 59: 3215 - 3228.

Williams, M.W. 1994. Factors influencing chemical thinning and update on new chemical thinning agents. *Compact Fruit Tree* 27: 115 - 122.

Yuan, R. and Greene, D.W. 2000. Benzyladenine as chemical thinner for 'McIntosh' apples. I. Fruit thinning effects and associated relationships with photosynthesis, assimilate translocation, and non-structural carbohydrates. *J. Amer. Soc. Hort. Sci.* 125:169 - 176.

Tables

Table 1. Orchard details of 'Early Bon Chrétien' trials.

	Site		
	La Plaisante 2004/5	Buchuland 2006/7	La Plaisante 2006/7
Year planted	1997	1995	1997
Rootstocks	BP3	BP3	BP3
Spacing	4.5 x 1.5 m	4.5 x 1.5 m	4.5 x 1.5 m
Training system	Central leader	Central leader	Central leader
Cross pollinators	none	none	none
Yield 2002/3	41 ton/ha		
Yield 2003/4	45 ton/ha		
Yield 2004/5		55 ton/ha	49 ton/ha
Yield 2005/6		53 ton/ha	40 ton/ha
Full bloom	15 September 2004	9 September 2006	9 September 2006
Hand thinning	3 November 2004	18 October 2006 21 October 2006	24 October 2006
Harvest	27 December 2004 12 January 2005	3 January 2007 18 January 2007	4 January 2007

Table 2. Spray information of 'Early Bon Chrétien' trials.

	Site		
	La Plaisante 2004/5	Buchuland 2006/7	La Plaisante 2006/7
6-benzyladenine (BA)			
Date*	28 September 2004	22 September 2006	28 September 2006
Temperature °C	16.8	16.5	17.0
Relative Humidity (%)	71.5	57.0	76.0
Naphthylacetamide (NAD)			
Date*	28 September 2004	8 September 2006	13 September 2006
Temperature °C	16.8	18.0	17.5
Relative Humidity (%)	71.5	51.0	69.0

* Spray date

Table 3. Effect of different 6-benzyladenine (BA) rates and naphthylacetamide (NAD) on fruit set on two tagged branches and number of fruits thinned by hand on 'Early Bon Chrétien' pear.

Treatment	Average fruit set per cluster on two tagged branches*	Average number of fruits thinned by hand per tree
La Plaisante 2004/5		
Control	1.04 a	100.7 a
BA 50 mg.l^{-1}	0.77 b	74.9 ab
BA 100 mg.l^{-1}	0.78 b	58.6 b
BA 150 mg.l^{-1}	0.42 c	56.2 b
NAD 30 mg.l^{-1}	0.61 bc	67.8 ab
Significance level	*<.0001*	*0.0695*
Buchuland 2006/7		
Control	0.67 a	357.0 a
BA 100 mg.l^{-1}	0.39 c	264.0 bc
BA 150 mg.l^{-1}	0.33 c	208.0 c
NAD 40 mg.l^{-1}	0.54 b	311.0 ab
Significance level	*<.0001*	*0.0013*
La Plaisante 2006/7		
Control	0.54 ab	140.2 ns
BA 100 mg.l^{-1}	0.40 b	108.2 ns
BA 150 mg.l^{-1}	0.43 b	124.8 ns
NAD 40 mg.l^{-1}	0.64 a	159.7 ns
Significance level	*0.0118*	*0.1568*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Number of fruits after natural fruit drop /number of flower clusters at bloom.

Table 4. Effect of different 6-benzyladenine (BA) rates and naphthylacetamide (NAD) on 'Early Bon Chrétien' pear yield.

Treatment	Yield efficiency (kg/cm trunk circumference)	Estimated yield (ton/ha)
La Plaisante 2004/5		
Control	1.19 a	53.32
BA 50 mg.l^{-1}	1.23 a	55.80
BA 100 mg.l^{-1}	1.08 a	48.34
BA 150 mg.l^{-1}	0.86 b	39.39
NAD 30 mg.l^{-1}	0.85 b	39.62
Significance level	*0.0006*	-
Buchuland 2006/7		
Control	1.14 ns	55.33
BA 100 mg.l^{-1}	1.10 ns	56.07
BA 150 mg.l^{-1}	0.98 ns	56.07
NAD 40 mg.l^{-1}	1.08 ns	54.76
Significance level	*0.3180*	-
La Plaisante 2006/7		
Control	1.15 ns	55.22
BA 100 mg.l^{-1}	1.05 ns	49.76
BA 150 mg.l^{-1}	1.03 ns	51.61
NAD 40 mg.l^{-1}	1.16 ns	56.82
Significance level	*0.2551*	-

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 5. Effect of different 6-benzyladenine (BA) rates and naphthylacetamide (NAD) on fruit size of 'Early Bon Chrétien' pear at La Plaisante Estate, Wolseley 2004/5 season.

Treatment	Average fruit diameter (mm)	Average fruit length (mm)	Average fruit weight (g)
Control	64.20 ns	75.14 b	146.55 b
BA 50 mg.l^{-1}	64.90 ns	77.79 a	153.88 ab
BA 100 mg.l^{-1}	65.10 ns	77.58 a	154.61 a
BA 150 mg.l^{-1}	65.50 ns	77.84 a	158.09 a
NAD 30 mg.l^{-1}	65.30 ns	78.27 a	156.12 a
Significance level	*0.1387*	*0.0156*	*0.0563*
LSD	1.11	1.90	7.89
Covariate analysis			
Fruit set *	*0.0084*	*0.0934*	*0.0823*
Treatment	*0.9487*	*0.1591*	*0.6215*
Hand thinning *	*0.0701*	*0.0051*	*0.0029*
Treatment	*0.1591*	*0.0842*	*0.3241*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Fruit set on two tagged branches or number of fruit removed by hand thinning used as covariates.

Table 6. Effect of different 6-benzyladenine (BA) rates and naphthylacetamide (NAD) on fruit size of 'Early Bon Chrétien' pear at Buchuland Farm, Ceres 2006/7 season.

Treatment	Average fruit diameter (mm)	Average fruit length (mm)	Average fruit weight (g)
Control	66.35 ns	83.27 ns	168.27 ns
BA 100 $mg.l^{-1}$	66.39 ns	83.22 ns	169.45 ns
BA 150 $mg.l^{-1}$	67.45 ns	84.13 ns	175.08 ns
NAD 40 $mg.l^{-1}$	65.79 ns	83.19 ns	164.86 ns
Significance level	*0.1596*	*0.7480*	*0.2287*
LSD	1.47	2.05	9.95
Covariate analysis			
Fruit set*	*0.1532*	*0.3525*	*0.1400*
Treatment	*0.3640*	*0.8668*	*0.4932*
Hand thinning*	*0.2941*	*0.0409*	*0.2044*
Treatment	*0.3077*	*0.9050*	*0.4276*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Fruit set on two tagged branches or number of fruit removed by hand thinning used as covariates.

Table 7. Effect of different 6-benzyladenine (BA) rates and naphthylacetamide (NAD) on fruit size of 'Early Bon Chrétien' pear at La Plaisante Estate, Wolseley 2006/7 season.

Treatment	Average fruit diameter (mm)	Average fruit length (mm)	Average fruit weight (g)
Control	65.56 ns	80.63 ns	158.11 ns
BA 100 $mg.l^{-1}$	66.99 ns	81.68 ns	166.37 ns
BA 150 $mg.l^{-1}$	66.64 ns	80.62 ns	164.56 ns
NAD 40 $mg.l^{-1}$	66.06 ns	81.68 ns	162.59 ns
Significance level	*0.2892*	*0.6951*	*0.5083*
LSD	1.50	2.54	11.57
Covariate analysis			
Fruit set*	*0.7709*	*0.9296*	*0.7342*
Treatment	*0.6021*	*0.6550*	*0.6830*
Hand thinning*	*0.2370*	*0.0221*	*0.1082*
Treatment	*0.5185*	*0.4058*	*0.6551*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Fruit set on two tagged branches or number of fruit removed by hand thinning used as covariates.

Table 8. Effect of different 6-benzyladenine (BA) rates and naphthylacetamide (NAD) on fruit quality of 'Early Bon Chrétien' pear.

Treatment	% Fruit not exportable due to solid russet	% Fruit not exportable due to retiform russet	% Fruit with calyx-end ribbing
La Plaisante 2004/5			
Control	0.40 ns	0.00 ns	0.00
BA 50 mg.l^{-1}	0.80 ns	0.40 ns	0.00
BA 100 mg.l^{-1}	0.40 ns	0.00 ns	0.00
BA 150 mg.l^{-1}	0.40 ns	0.42 ns	0.00
NAD 30 mg.l^{-1}	0.80 ns	0.40 ns	0.00
Significance level	*0.9675*	*0.6816*	-
Buchuland 2006/7			
Control	0.40 ns	5.20 ns	5.60 ns
BA 100 mg.l^{-1}	0.80 ns	6.00 ns	7.20 ns
BA 150 mg.l^{-1}	1.60 ns	7.60 ns	10.80 ns
NAD 40 mg.l^{-1}	2.00 ns	6.80 ns	7.60 ns
Significance level	*0.1710*	*0.8118*	*0.4106*
La Plaisante 2006/7			
Control	0.40 ns	19.20 a	10.00 ns
BA 100 mg.l^{-1}	0.80 ns	11.20 b	5.60 ns
BA 150 mg.l^{-1}	1.20 ns	14.40 ab	7.20 ns
NAD 40 mg.l^{-1}	0.80 ns	8.80 b	10.80 ns
Significance level	*0.8741*	*0.0397*	*0.2487*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 9. Effect of different 6-benzyladenine (BA) rates and naphthylacetamide (NAD) on seed number of 'Early Bon Chrétien' pear.

Treatment	Number of well-developed seeds per fruit	Number of aborted seeds per fruit
La Plaisante 2004/5		
Control	0.98 b	8.60 a
BA 50 mg.l^{-1}	1.03 b	8.65 a
BA 100 mg.l^{-1}	1.13 ab	8.48 a
BA 150 mg.l^{-1}	1.43 a	8.06 b
NAD 30 mg.l^{-1}	0.95 b	8.58 a
Significance level	*0.0305*	*0.0082*
Buchuland 2006/7		
Control	1.26 b	8.58 a
BA 100 mg.l^{-1}	1.52 ab	8.42 ab
BA 150 mg.l^{-1}	1.74 a	8.05 c
NAD 40 mg.l^{-1}	1.62 ab	8.20 bc
Significance level	*0.0626*	*0.0279*
La Plaisante 2006/7		
Control	0.20 ns	9.70 ns
BA 100 mg.l^{-1}	0.10 ns	9.77 ns
BA 150 mg.l^{-1}	0.34 ns	9.53 ns
NAD 40 mg.l^{-1}	1.19 ns	9.69 ns
Significance level	*0.1225*	*0.3441*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 10. Effect of different 6-benzyladenine (BA) rates and naphthylacetamide (NAD) on return bloom of 'Early Bon Chrétien' pear at La Plaisante Estate, Wolseley 2004/5 season.

Treatment	Percentage return bloom on two tagged branches**
Control	5.7 c
BA 50 $mg.l^{-1}$	11.7 ab
BA 100 $mg.l^{-1}$	11.7 ab
BA 150 $mg.l^{-1}$	13.8 a
NAD 30 $mg.l^{-1}$	8.8 bc
Significance level	*0.0006*
LSD	3.573
Covariate analysis	
Fruit set*	*0.0036*
Treatment	*0.0176*
Hand thinning*	*0.0074*
Treatment	*0.0033*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Fruit set on two tagged branches or number of fruit removed by hand thinning used as covariates.

** Return Bloom (reproductive buds × 100/reproductive + vegetative buds).

Table 11. Effect of different 6-benzyladenine (BA) rates and naphthylacetamide (NAD) on return bloom of 'Early Bon Chrétien' in the 2006/7 season.

Treatment	Percentage return bloom on two tagged branches at La Plaisante Estate, Wolseley**	Percentage return bloom on two tagged branches at Buchuland Farm, Ceres**
Control	20.5 ab	26.0 b
BA 100 mg.l^{-1}	24.5 a	37.7 a
BA 150 mg.l^{-1}	24.5 a	36.9 a
NAD 40 mg.l^{-1}	18.1 b	25.9 b
Significance level	*0.1219*	*0.0013*
LSD	6.3	7.24
Covariate analysis		
Fruit set*	*0.0026*	*0.0010*
Treatment	*0.6510*	*0.0349*
Hand thinning*	*0.1674*	*0.2108*
Treatment	*0.2937*	*0.0038*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Fruit set on two tagged branches or number of fruit removed by hand thinning used as covariates.

**Return Bloom (reproductive buds × 100/reproductive + vegetative buds).

Figures

Climatic data

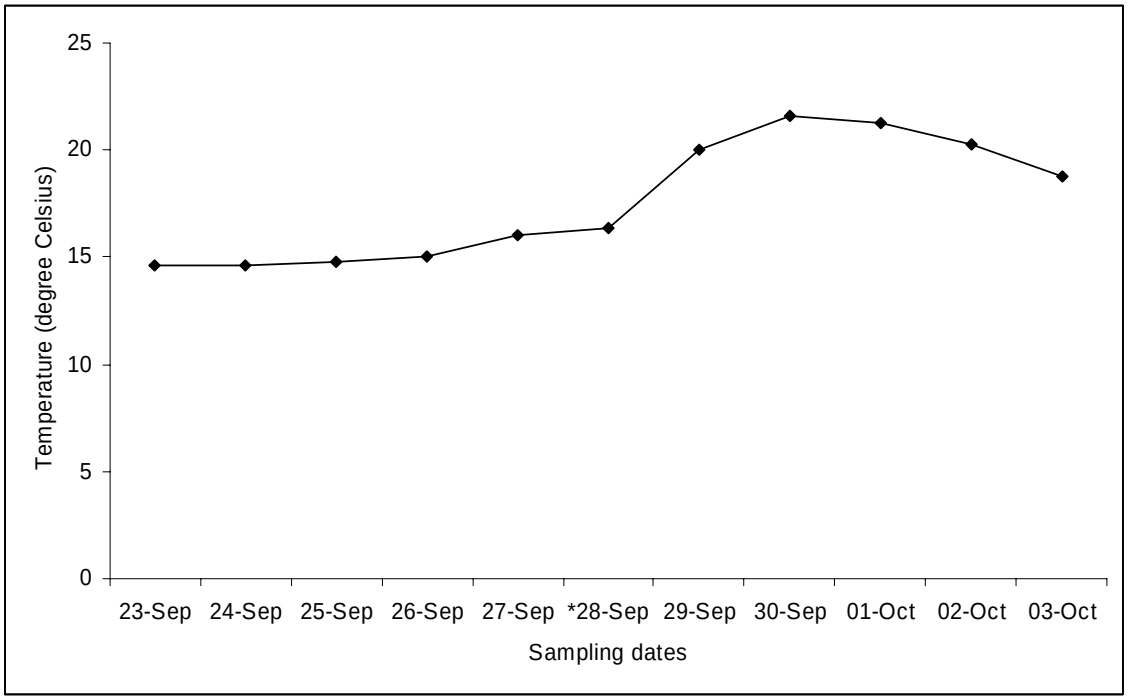

Fig. 1. Mean daily temperatures from 24 September to 3 October 2004 at La Plaisante Estate, Wolseley.

* Spray date

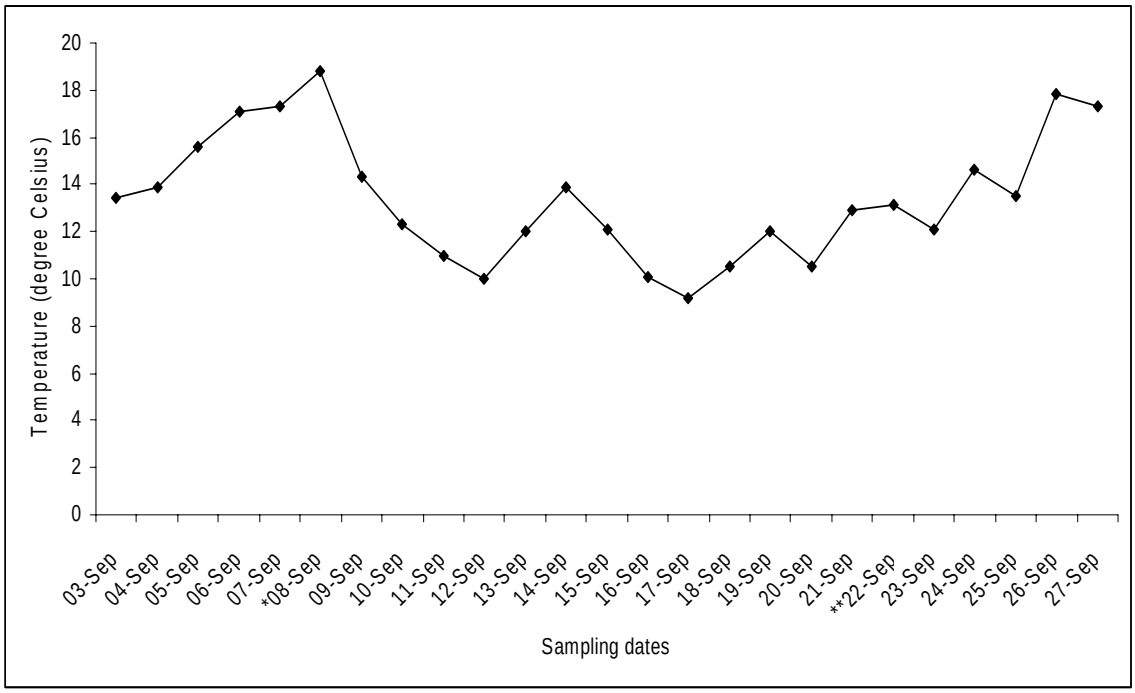

Fig. 2. Mean daily temperatures from 3 to 27 September 2006 at Buchuland Farm,Ceres.

* Naphthylacetamide (NAD) spray date

** 6-benzyladenine (BA) spray date

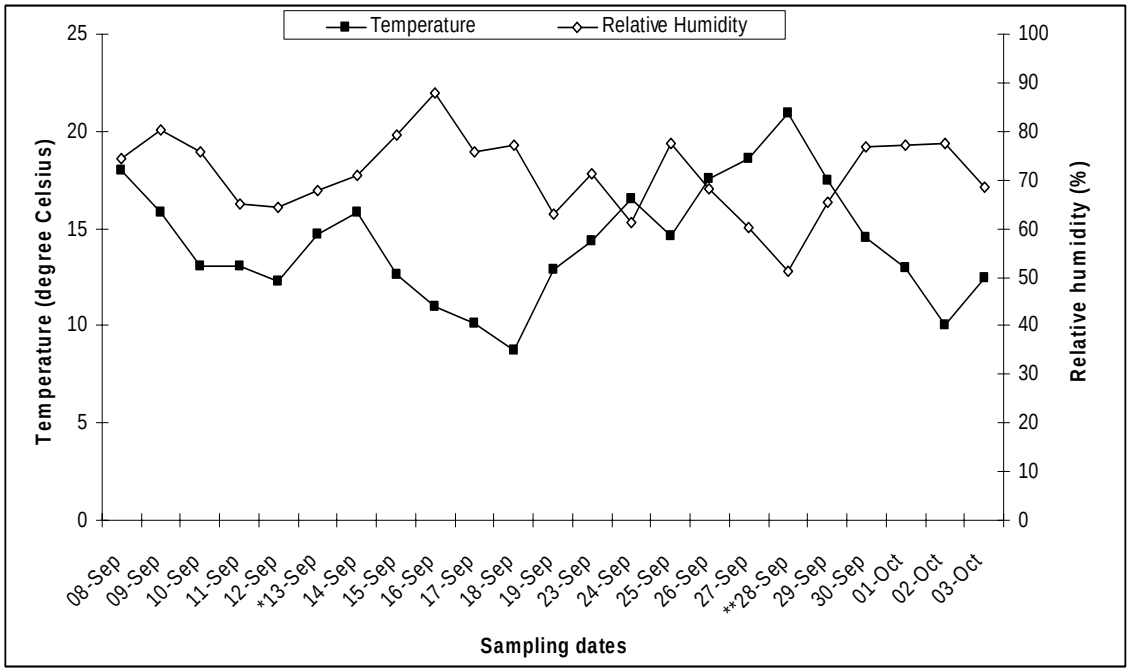

Fig. 3. Mean daily temperature and relative humidity from 8 September to 3 October 2006 at La Plaisante Estate, Wolseley.

* Naphthylacetamide (NAD) spray date

** 6-benzyladenine (BA) spray date

Fruit size distribution

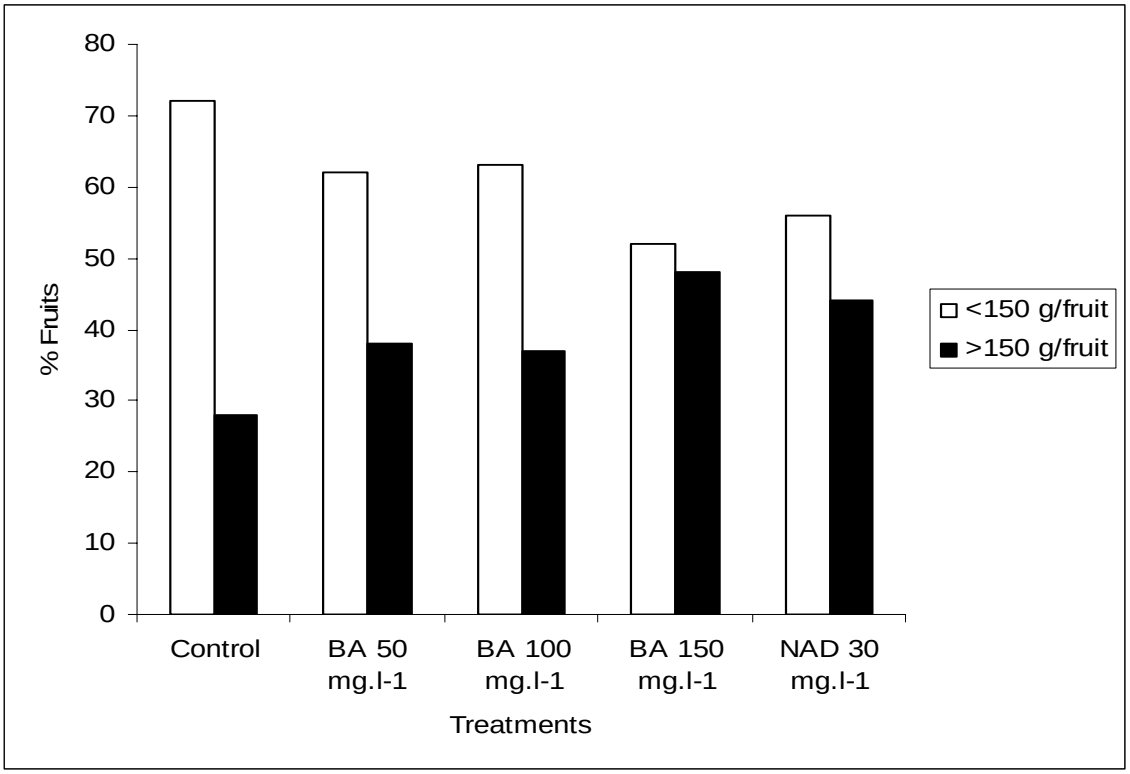

Fig. 4. Effect of different BA rates and NAD on fruit size distribution in 'Early Bon Chrétien' fruit at La Plaisante Estate, Wolseley 2004/5 season.

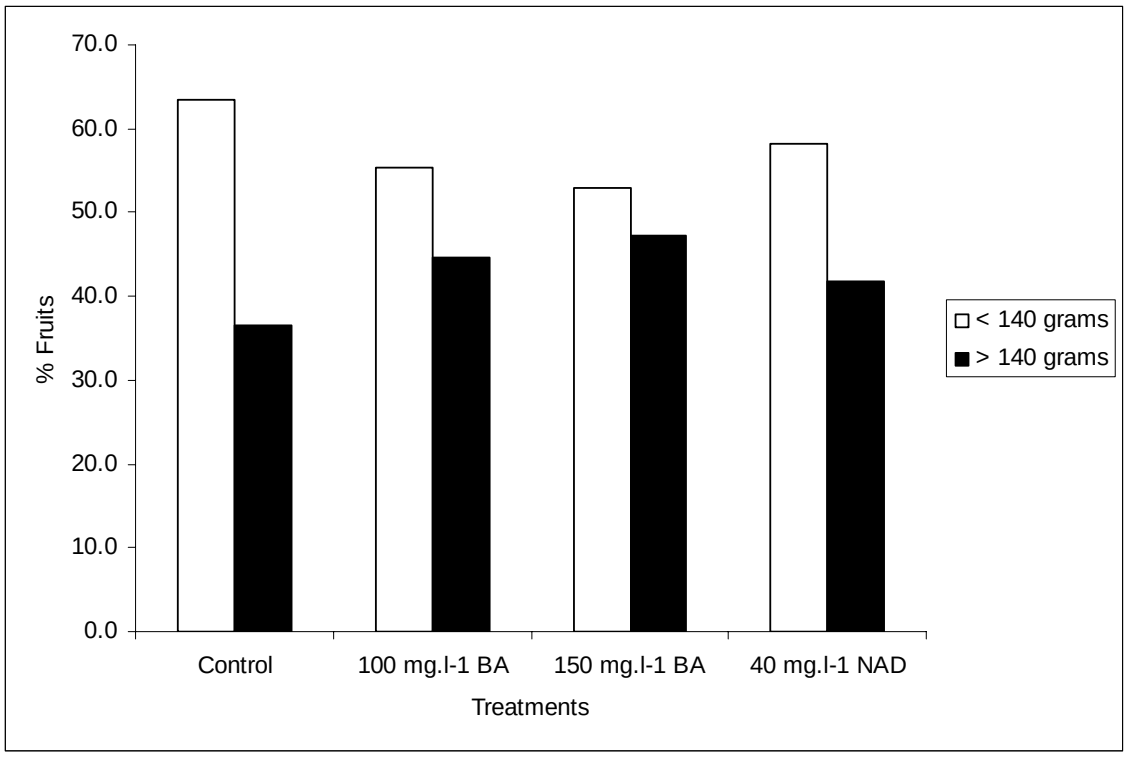

Fig. 5. Effect of different BA rates and NAD on fruit size distribution in 'Early Bon Chrétien' fruit at La Plaisante Estate, Wolseley 2006/7 season.

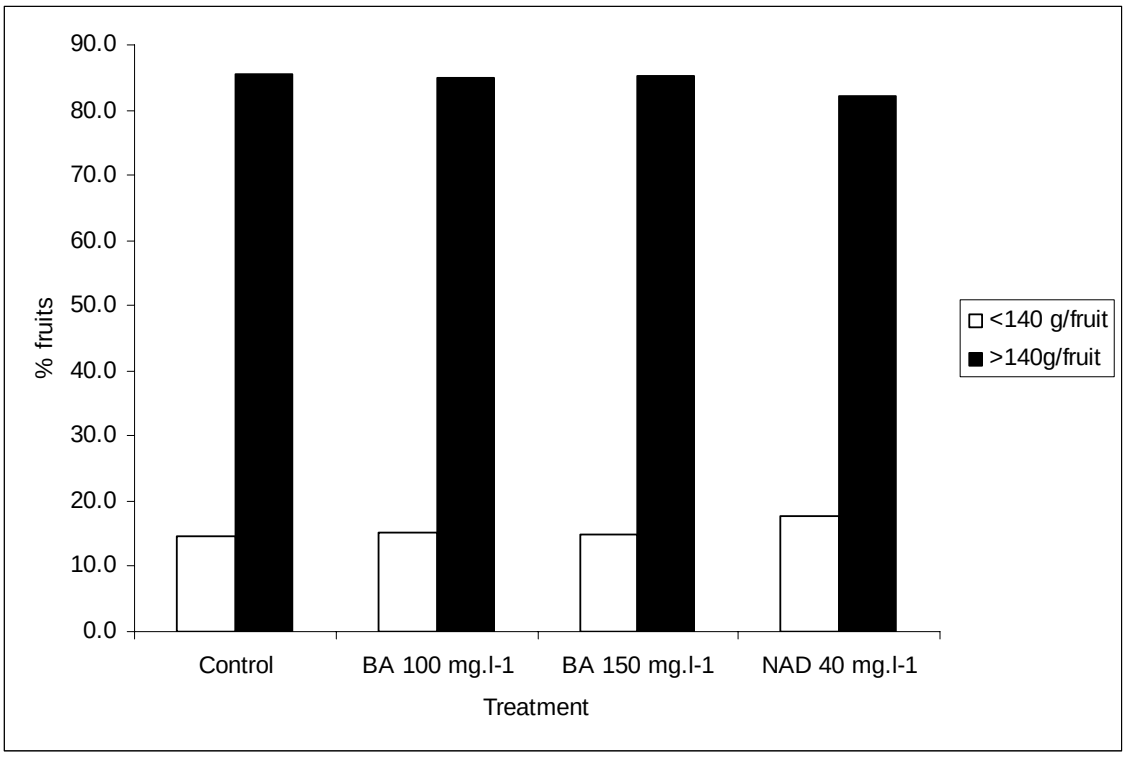

Fig. 6. Effect of different BA rates and NAD on fruit size distribution in 'Early Bon Chrétien' fruit at Buchuland, Ceres 2006/7 season.

Plates

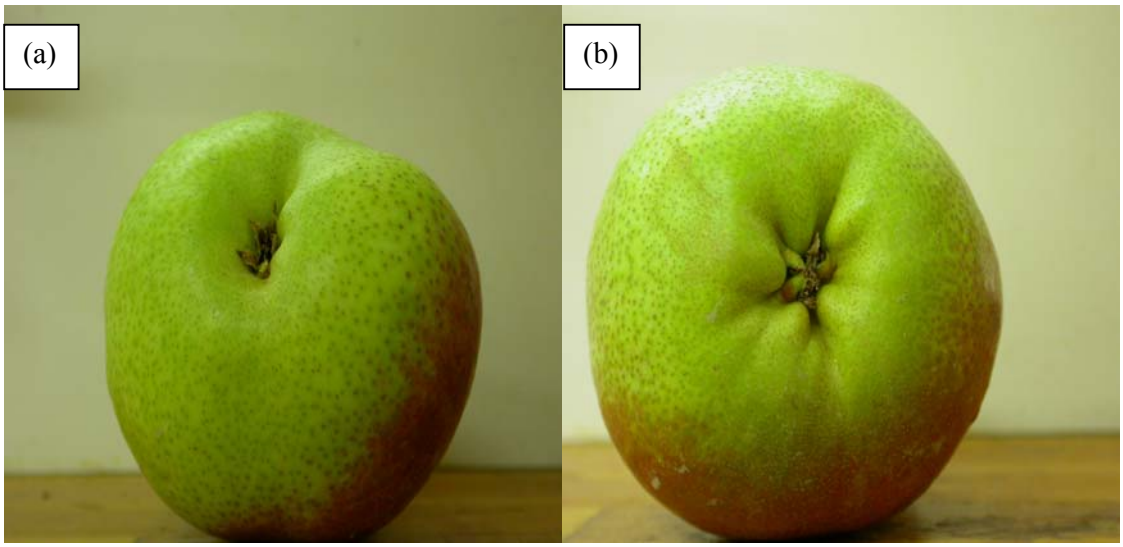

Plate 1. (a) Pear without calyx-end ribbing and (b) Pear with calyx-end ribbing

CHAPTER 3

Chemical thinning of 'Forelle' pear with 6-benzyladenine

Abstract

'Forelle' is the main blushed pear cultivar grown in South Africa. It often requires fruit thinning to reach a marketable fruit size at harvest and to achieve regular yields by preventing alternate bearing. The effect of 6-benzyladenine (BA) at rates of 100 to 200 $mg.l^{-1}$, on crop load, fruit size and return bloom of 'Forelle' was evaluated in three experiments on three sites in the Western Cape, South Africa in the 2006/7 and 2007/8 seasons. In the first experiment, 100, 125 and 150 $mg.l^{-1}$ rates of BA were evaluated. The highest rate, 150 $mg.l^{-1}$ was relatively effective, whilst lower rates were ineffective in reducing crop load and improving fruit size. In the second experiment, 150 $mg.l^{-1}$, 200 $mg.l^{-1}$ and a split application of 3 x 50 $mg.l^{-1}$ BA were evaluated. The BA treatments did not reduce crop load, however, they improved fruit size significantly. BA did not significantly improve return bloom. The 200 $mg.l^{-1}$ rate was the most effective treatment. The BA spays did not alter seasonal fruit growth. The following linear model fitted the fruit growth vs. time curve on unsprayed trees: Fruit diameter = 0.33 x d.a.f.b. + 5.54, $R^2 = 0.9901$, $P < .0001$. In the third experiment, 150 and 200 $mg.l^{-1}$ BA rates applied at three different application times, 8, 11 and 17 days after full bloom (d.a.f.b.) were evaluated. The effects of BA were largely additive, crop load and yield decreased whilst fruit size increased with increasing rate. There was a significant quadratic increase in BA efficacy with time of application, 11 d.a.f.b. applications were more effective than 8 and 17 d.a.f.b. applications in reducing crop load, and improving fruit size and fruit size distribution. BA sprays significantly improved return bloom relative to the control. BA did not affect fruit shape, seed numbers, calyx-end ribbing and fruit colour.

Keywords: benzyladenine; crop load; diameter; firmness; fruit size; rate; time.

Introduction

'Forelle' is characteristically a small, attractive, blushed pear cultivar which generally commands higher prices than green or fully red fruit. However, a major problem being experienced with this cultivar in South Africa is lack of fruit size (Marais, 1995; Huysamer, 1997). According to Webster (2002a), the problem of excessive fruit set and reduced fruit size at harvest is particularly severe with varieties which are intrinsically smaller than the

average fruit size. Fruit size and return bloom are improved commercially by reducing crop load. This affects carbohydrate partitioning, promotes vegetative growth and affects induction and differentiation of floral buds (Byers *et al.,* 1990).

6-benzyladenine (BA) is a promising post-bloom thinning agent of European pear cultivars (Wertheim, 2000; Webster, 2002a; b). BA promotes fruit growth directly by stimulating and prolonging the phase of mitotic cell division in developing fruit (Shargal *et al.,* 2006) and indirectly by stimulating fruit abscission (Wertheim, 2000; Webster, 2002a). According to Yuan and Greene (2000), BA promotes fruit abscission by inducing a temporary reduction in photosynthesis and increasing dark respiration, which leads to limited carbohydrate supply to the developing fruit. However, some researchers argue that BA does not appear to affect leaf assimilation (Stopar *et al.,* 1997; Wertheim, 2000). The current opinion is that BA promotes fruit abscission by stimulation of the growth of lateral side shoots, such as the bourse shoot (Greene and Autio 1989; Williams, 1994; Dennis, 2000). IAA transport out of these newly released lateral shoots may correlatively inhibit IAA export from part of the fruits sufficiently to induce their drop (Bangerth, 2000).

The unique ability of BA to increase fruit size without an apparent reduction in fruit numbers on trees (Bubán, 2000; Wertheim, 2000; Webster, 2002a), has led to the suggestion that, in some cases, low endogenous cytokinin levels of fruit, rather than crop load is the main cause of small fruit sizes (Flaishman *et al.,* 2001). Therefore, endogenous cytokinin levels in small fruited pear cultivars, such as the 'Forelle' and 'Conference', are not sufficient to allow the developing fruit to form adequate cell numbers for commercially acceptable sizes at harvest. BA is also known to stimulate flower-bud formation, thereby improving return bloom directly (Wertheim, 1990; 2000; Reynolds, 2004).

Unfortunately, the use of BA as a post-bloom thinning agent has often produced variable results, compromising grower acceptance (Dennis, 2000; Wertheim, 2000). This is usually due to tree, climatic factors as well as application time and rate. Among these factors, the grower has the greatest control over application time and rate. According to Marini (1998), the degree of fruit thinning is influenced by the fruit diameter at the time of application. The recommended application period of BA is when fruitlets are 7 to 12 mm (most often 10 to 12 mm) diameter, which is 14 to 21 d.a.f.b. (Bubán, 2000; Bertelsen, 2002). Any delay in fruit

thinning reduces its effect on the remaining fruit because the opportunity for much increase in cell division is lost (Jackson, 2003). This is because most cell division in pear fruit ceases 50 to 60 d.a.f.b. (Bain, 1961; Westwood, 1993).

The aims of this study were (i) to evaluate different BA rates, (ii) to compare single and split applications of BA and (iii) to determine the stage of fruit development/ application time which produce best thinning results on 'Forelle' pear.

Materials and methods

Experiment 1

Plant material

Three trials were conducted during the 2006/7 season on two farms in the Western Cape, South Africa. The experimental sites are located in a Mediterranean climatic region with cool, wet winters and hot, dry summers. Two orchards at La Plaisante Estate, situated in the Wolseley area (33°25′ S, 19°12′ E) and one orchard at Buchuland Farm, Ceres (33°15′ S, 19°15′ E) were used for the trials. Relevant orchard details for each site are presented in Table 1. Trees were selected for uniformity of size and blossom density at each site.

Treatments and experimental design

MaxCel ™, a commercially available product containing 1.9 % (w/w) of 6-BA was applied at low volume with a motorised knapsack sprayer at 1 000 $L.ha^{-1}$ at 8 to 12 mm fruit diameter. At each site, three rates 100, 125 and 150 $mg.l^{-1}$ were applied and compared to an unsprayed control. Surfactants were not added to the spray solution. Randomised complete block designs with 10 single-tree plot replications of four treatments were used at each site. Standard farm practices such as the application of commercial ProGibb® (GA_3) at 30 % bloom for fruit set, irrigation schedules and nutritional supplements were kept constant for all treatments. Weather conditions at spraying time in each trial are presented in Table 2. All treatments were hand thinned after the natural fruit drop period (Table 1) to 1 or 2 fruit per cluster to improve fruit distribution per cluster and enhance colour development (Theron *et al.,* 2002). Harvesting of trial fruit was undertaken on the same days as the commercial harvest on each farm.

Experiment 2

Plant material

The experiment was carried out in the 2007/8 season at Oak Valley Estate, which is situated in Grabouw (33° 19' S, 26° 36' E) in the Western Cape, South Africa. Relevant orchard details for this site are presented in Table 1. Trees were selected for uniformity of size and blossom density.

Treatments and experimental design

MaxCel ™, containing 1.9 % (w/w) of 6-BA was applied at 150 mg.l^{-1}, 200 mg.l^{-1} (at 8 to 12 mm fruit diameter) and a split application of 3 x 50 mg.l^{-1} (at 8 to 14 mm fruit diameter). These MaxCel ™ treatments were compared with an unsprayed control (see Table 2). All chemicals were applied with a motorised knapsack sprayer at 1 000 L.ha^{-1}, surfactants were not added to the spray solution. A randomised complete block design with 10 single-tree plot replications of four treatments was used for the trial. Commercial ProGibb® (GA_3) treatment was applied at 30 % bloom for fruit set as per standard farm practice. Weather conditions at spraying time in each trial are presented in Table 2. All treatments were hand thinned after the natural fruit drop period (Table 1) to 1 or 2 fruit per cluster to improve fruit distribution per cluster and enhance colour development (Theron *et al.*, 2002). Harvesting of experimental fruit was undertaken on the same day as the commercial harvest.

Experiment 3

Plant material

The same at Buchuland as in Experiment 1 was used.

Treatments and experimental design

MaxCel ™, containing 1.9 % (w/w) of 6-BA was applied at two rates, 150 and 200 mg.l^{-1}, to whole trees at three stages of fruit development (range of timings), namely 6 to 8 (8 d.a.f.b.), 8 to 10 (11 d.a.f.b.) and 10 to 12 (17 d.a.f.b.) mm fruitlet size. These MaxCel ™ treatments were compared with an unsprayed control. All chemicals were applied with a motorised knapsack sprayer at 1 000 L.ha^{-1}, surfactants were not added to the spray solution. A randomised complete block design with 10 single-tree plot replications of seven treatments was used for the trial. Commercial ProGibb® (GA_3) was applied at 30 % bloom for fruit set as

per standard farm practice. Weather conditions at spraying time in each trial are presented in Table 2. All treatments were hand thinned after the natural fruit drop period (Table 1) to 1 or 2 fruit per cluster to improve fruit distribution per cluster and enhance colour development (Theron *et al.,* 2002). Harvesting of experimental fruit was undertaken on the same day as the commercial harvest.

Data collected

At bloom, two representative branches were tagged in the lower sector of the trees and the number of flower clusters on these branches was recorded. Trunk circumference was measured approximately 20 cm above the graft union. After the natural fruit drop period, fruit set per cluster on the tagged branches was recorded, as well as the number of fruit removed by hand thinning per tree. In Experiment 2, five fruits were tagged per replication (tree) and fruit diameter was measured at weekly intervals with a vernier calliper, from hand thinning date to harvest.

At harvest, the fruit from each tree were weighed to determine the yield for each treatment. A randomly selected sample of 25 fruits per tree was collected and analysed for the following fruit quality parameters; fruit diameter, length, weight, number of developed seeds and seeds with aborted embryos per fruit, and fruit with calyx-end ribbing. Fruit firmness and amount of blush per fruit were measured in the 2007/8 season. Fruit firmness was measured with a GÜSS fruit texture analyser (Model GS-14, Guss Manufacturing Ltd., Strand, South Africa, with a plunger diameter of 8 mm) directly into the flesh on paired, opposite sides of each fruit. The amount of blush (colour) was evaluated on a scale of 1 to 6 (1 = most blush; 6 = least blush) using the Unifruco colour chart number P25. Calyx-end ribbing was determined by visual observation (see Chapter 2).

The remainder of the fruit were sample graded, and pack-out percentage was determined (average 2 bins per treatment). Grading data were expressed as percentage of fruit larger or smaller than 140 grams. Return bloom was monitored during the following season on branches tagged for fruit set counts, by counting the vegetative and reproductive buds that sprouted on these two tagged branches. The reproductive buds were expressed as a percentage of the total number of buds.

2.4 Statistical analysis

The General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) was used to analyse the data (SAS® 9.1.2, SAS Institute Inc, 2004, Cary, NC). In the 2007/8 season (Experiment 2 and 3), fruit yield, size and return bloom were analysed using fruit set and number of fruits thinned by hand as covariates. In Experiment 2, a linear regression equation of the form $Y = bX + c$ was fitted to the data, where Y is the average fruit diameter (n = 5; mm), X is time (d.a.f.b.), b is the regression coefficient and c is the intercept.

Results

Experiment 1

At the La Plaisante site (Orchard 1 and 2), there were no significant differences or apparent trends among treatments in terms of fruit set and the number of fruitlets that had to be thinned by hand (Table 3). At the Buchuland site, BA significantly reduced fruit set ($p = 0.0067$) and the number of fruits thinned by hand ($p = 0.0321$). The 125 and 150 $mg.l^{-1}$ rates significantly reduced fruit set, by approximately 35 % of the control (Table 3). The lowest BA rate, 100 $mg.l^{-1}$, reduced fruit set by approximately 18 % of the control, however, this reduction was not statistically significant (Table 3). The number of fruitlets that had to be thinned by hand was significantly reduced by the highest rate, 150 $mg.l^{-1}$, by approximately 26 % of the control (Table 3). The two lower rates, 100 and 125 $mg.l^{-1}$ also reduced the number of fruitlets that had to be thinned by hand, however these reductions were not statistically significant (Table 3).

No significant differences or apparent trends among treatments were observed on yield efficiency (Table 4), average fruit diameter, length, and weight at any of the sites in the 2006/7 season (Table 5). No discernable shift in fruit size distribution was observed at any of the sites (Fig. 5; 6; 7). However, at the Buchuland site, ± 55 % of the fruit from all treatments were bigger than 140 grams (Fig. 7). The fruit grade distribution data was not statistically analysed due to it being a pooled sample from the different replications. BA did not affect fruit shape and seed abortion at any of the sites in any season (Table 6).

No significant differences or apparent trends among treatments were observed at any site on return bloom (Table 7). At the La Plaisante site (Orchard 2), the 125 mg.l^{-1} rate resulted in the highest increase in return bloom by ± 100 % of the control (Table 7). The highest and lowest BA rates, 100 and 150 mg.l^{-1}, increased return bloom by approximately 87 % of the control (Table 7). The BA sprays did not improve return bloom at the La Plaisante (Orchard 1) and Buchuland sites (Table 7).

Experiment 2

There were no statistically significant differences in terms of fruit set and the number of fruitlets that had to be thinned by hand at the Oak Valley site, however, fruit set decreased with increased BA rate (Table 8). The highest rate, 200 mg.l^{-1}, reduced fruit set by approximately 32 % of the control (Table 8). The lower rates, 150 and 3 x 50 mg.l^{-1} reduced fruit set by ± 20 and ± 23 % of the control, respectively (Table 8). No apparent trend among treatments was observed for the number of fruitlets that had to be thinned by hand at this site (Table 8).

Significant differences were found in yield efficiency were found between treatments at the Oak Valley site (Table 9). Although not significant, the 3 x 50 mg.l^{-1} treatment increased yield by approximately 15 % relative to the control. When adjusted for fruit set by covariate analysis, the BA treatments became more significant (Table 9). The number of fruits thinned by hand as a covariate did not significantly affect yield (Table 9). All BA treatments significantly increased fruit diameter and length relative to the untreated control. The 200 mg.l^{-1} rate was the most effective treatment (Table 10). All BA treatments improved fruit weight relative to the control, however, these increases were not statistically significant (Table 10). The highest BA rate, 200 mg.l^{-1}, was the most effective treatment, increasing fruit weight by approximately 12 % of the control, while BA at 150 and 3 x 50 mg.l^{-1} increased fruit weight by ± 9 % of the control (Table 10). No significant differences or apparent trends among treatments for fruit firmness were observed. Fruit set and the number of fruits thinned by hand as covariates, did not significantly affect fruit diameter, weight and firmness (Table 10).

No discernable shift in fruit size distribution was observed with the BA rates evaluated (Fig.

8). The fruit grade distribution data was not statistically analysed due to it being a pooled sample from the different replications. The BA sprays did not significantly alter seasonal fruit growth in terms of the mean fruit diameter (n = 5) (Fig. 9). The following linear model fitted the fruit growth vs. time curve of unsprayed trees: Fruit diameter = 0.33 x d.a.f.b. + 5.54, R^2 = 0.9901, P *<.0001* (Fig. 10). No significant differences or apparent trends among treatments were observed in terms of fruit shape, colour and seed abortion (Table 11).

The BA treatments improved return bloom relative to the unsprayed control, however none of these increases were statistically significant (Table 10). The 200 $mg.l^{-1}$ rate was the most effective treatment, improving return bloom by ± 40 % of the control. Fruit set and number of fruits thinned by hand were not significant covariates, however, when adjusted for fruit set, the treatments became significant (Table 10).

Experiment 3

There were no statistically significant linear or quadratic interactions between BA rate and timing of application for any of the parameters evaluated (Table 12; 13; 15; 16; 17). BA rate did not significantly affect fruit set on the tagged branches, however, the higher rate tended to be more aggressive (Table 12). The timing of the application also did not affect fruit set on the two tagged branches significantly, although the latest application seemed the least effective (Table 12). The BA sprays had a statistically significant effect on the number of fruits that had to be thinned by hand (*p <.0001*). The 200 $mg.l^{-1}$ rate was more effective, reducing the number of fruits that had to be thinned by hand by ± 46 % of the control, compared to the ± 40 % reduction induced with the 150 $mg.l^{-1}$ rate (Table 12). There was a statistically significant quadratic reduction (*p* = 0.0419) in the number of fruits that had to be thinned by hand with timing of BA application (Table 12).

Statistically significant differences were found in yield efficiency between treatment (p = 0.0002). The rate of BA used, did not have a notable effect on yield efficiency. There was a statistically significant quadratic reduction (p = 0.0450) in the yield efficiency with timing of BA application (Table 13). Fruit set as a covariate did not significantly affect yield. The significance of the BA treatments decreased with hand thinning as a covariate (Table 14).

The effects of the BA treatments on fruit diameter, length and weight were statistically significant. Fruit diameter, length and weight were significantly increased with the higher rate of BA (Table 15). There was a quadratic decrease in fruit diameter the later BA was applied, while the quadratic response of fruit weight with timing of BA application indicated an optimum timing at an average fruit size of 8 to 10 mm (Table 15). There was a statistically significant linear ($p = 0.0231$) increase in fruit firmness the later the BA application was made (Table 15).

Fruit set was not a significant covariate, whilst the number of fruits that had to be thinned by hand was a significant covariate for the fruit diameter, length, weight and firmness at harvest (Table 14). When fruit diameter, length, weight and firmness were adjusted for the number of fruits thinned by hand, the treatment means for fruit diameter and weight became more significant (Table 14). On the other hand, the treatment means for fruit length and firmness became less significant when adjusted for the number of fruits thinned by hand, (Table 14).

Fruit size distribution at Buchuland was generally poor in this season (Fig. 11). However, BA sprays at the higher rate generally produced more fruits larger than 140 grams. The fruit size distribution data was not statistically analysed due to it being a pooled sample from the different replications. BA applications at 8 to 10 and 10 to 12 mm were more effective than applications at 6 to 8 mm fruit size (Fig. 11). There was a somewhat quadratic response of BA with respect to application time for both rates (Fig. 11).

The treatments did not significantly affect fruit shape and seed abortion (Table 16). BA significantly ($p = 0.0003$) improved return bloom (Table 17), but no significant difference was found between the two rates ($p = 0.6444$) or the timings. Fruit set and number of fruit that had to be thinned by hand were significant covariates for return bloom (Table 14). When return bloom was adjusted for these covariates, the treatments became less significant (Table 14).

Discussion

Fruit set and number of fruits thinned by hand

The 100 and 125 mg.l^{-1} BA rates were ineffective in reducing fruit set and the number of fruitlets that had to be thinned by hand (Table 3), whilst the 150 and 200 mg.l^{-1} rates were relatively effective (Table 3; 8; 12). Therefore, lower rates of BA are not sufficient to reduce fruit set of 'Forelle'. BA at 100 mg.l^{-1} failed to reduce fruit set of 'Conference' (Wertheim, 2000; Vilardell *et al.,* 2005), but reduced fruit set on 'Clara Frijs' and 'Packham's Triumph' pear trees (Bertelsen, 2002; Bound and Mitchell, 2002). In recent European trials, 200 mg.l^{-1} BA significantly reduced fruit set on 'Conference' (Wertheim, 2000; Vilardell *et al.,* 2005) and 'Williams Bon Chrétien' pear trees (Dussi *et al.,* 2008). BA at 100 and 150 mg.l^{-1} significantly reduced fruit set on 'Early Bon Chrétien' (Chapter 2).

It has been demonstrated that BA is effective when there is an increase and ineffective when there is a decrease in mean daily temperatures 5 to 10 days after application (Marini, 1998; Bubán and Lakatos 2000). Mean daily temperatures decreased ± 5 days after BA application at the La Plaisante site in 2006 (Fig. 1), whilst an increase in mean daily temperatures was observed ± 5 days after BA application at the Buchuland site in the same season (Fig. 2). This probably contributed to the negative thinning results obtained with BA at the La Plaisante site in the 2006/7 season and the positive thinning results obtained with BA at the Buchuland site in the same season (Table 3). However, whilst mean daily temperatures increased ± 5 days after BA application (the 150 and 200 mg.l^{-1} treatments), BA did not significantly reduce fruit set at the Oak Valley site in 2007 (Fig. 3). This is probably because BA was applied late (22 d.a.f.b.) at this (Oak Valley) site (Table 1; 2). Time of application did not have a significantly affect fruit set at the Buchuland site in 2007, however, the 11 d.a.f.b. (8 to 10 mm average fruit diameter) was more effective (Table 12).

There was a significant quadratic reduction ($p = 0.0419$) in the number of fruitlets that had to be thinned by hand with timing of BA application (Table 12). This indicates that applying BA at an average fruit size of 8 to 10 mm (11 d.a.f.b.) will yield the highest reduction in fruit set and the number of fruitlets that have to be thinned by hand and thus reduces labour costs. The highest levels of competition between fruitlets for assimilates was probably around 11

d.a.f.b. It is highly likely that the earlier application (6 to 8 mm fruitlet size or 8 d.a.f.b.) was made during a period of less inter-fruit competition because at this time, most of the fruits will not yet have developed strong vascular connections, therefore there is likely to be some degree of uniformity in sink strength. It must also be noted that there was a sharp decrease in mean daily temperatures ± 5 days after the BA application 8 d.a.f.b. (Fig. 4), this could have contributed to the negative results. At 8 to 10 mm fruitlet size i.e. 11 d.a.f.b., some fruits have developed well differentiated vascular connections, therefore, there is less uniformity in sink strength and some fruits are more competitive than others which stimulates fruit drop. During the later application period (10 to 12 mm fruitlet size i.e. 17 d.a.f.b.), most of the fruits will have developed vascular connections and become active sinks, thus less fruit drop occurs despite the sharp increase in mean daily temperatures 5 days after BA application at this timing (Fig. 4). It must also be noted that at 17 d.a.f.b., a considerable amount of natural fruit drop may have occurred, rendering thinning less effective.

Temperature before, during and after BA application has a profound effect on thinning results (Bubán, 2000; Bubán and Lakatos 2000). The optimum temperature for BA application is ± 18 °C (Bound *et al.,* 1997a). The 11 d.a.f.b. BA applications were made at sub-optimum (13 °C) temperatures, whilst the 8 and 17 d.a.f.b. applications were made at temperatures of 18 °C and 16.5 °C respectively (Table 2). No appreciable differences in mean daily temperatures 5 days (fluctuating between 7.4 and 11.6 °C) after the 11 d.a.f.b. application was observed (Fig. 4). Due to sub-optimum temperatures experienced during and after BA application, the 11 d.a.f.b. timing is expected to be the relatively ineffective. However, high relative humidity (fluctuating between 70 and 80 %) was experienced 5 days after BA application (Fig.4). This probably improved BA efficacy at this application timing because humid conditions before or after spraying a thinning compound reduces drying time which in turn increases absorption through the fruit and leaves, thus improving the thinning results obtained (William, 1994; Webster, 2002a; Wertheim, 2000).

Fruit yield, size and firmness

Apart from Experiment 3, the BA treatments did not significantly affect yield efficiency (Table 4; 9; 13). BA rates below 150 $mg.l^{-1}$ did not improve fruit size at harvest (Table 5). Whilst BA at a rate of 100 $mg.l^{-1}$ increased average fruit size of 'Clara Frijs' (Bertelsen,

2002), 'Spadona' and 'Coscia' pear (Stern and Flaishman, 2003), it did not increase fruit size on 'Conference' (Wertheim, 2000). According to Flaishman *et al.* (2001), low endogenous cytokinin levels of fruit, rather than crop load is the main cause of small fruit sizes. Therefore, the levels of endogenous cytokinins in 'Forelle' are insufficient to allow the fruit to form adequate cell numbers for commercially acceptable sizes at harvest (Stern *et al.,* 2002). Thus, as a small-fruited pear cultivar, 'Forelle' probably requires higher BA rates of more than 200 $mg.l^{-1}$ to significantly increase fruit size to commercially acceptable levels.

The results from Experiments 2 and 3 indicate that fruit size parameters i.e. diameter, length and weight, increased with BA rate. The highest increase in fruit diameter and weight was obtained with the highest rate, 200 $mg.l^{-1}$ (Table 10; 15). The split application, 3 x 50 $mg.l^{-1}$ BA, significantly improved fruit diameter, whilst slightly improving fruit length, weight and seasonal fruit growth (Table 10; Fig. 5). This shows that a split application allows the level of cytokinins in the plant to be maintained for a longer period (Bound *et al.,* 1997b). Applying split-applications helps reduce the effect of unfavourable environmental conditions during spray application, however it may not be feasible as it requires more labour and is more expensive than single applications.

The rate and timing of BA applications are particularly critical to obtain the desirable thinning and size responses (Williams and Fallahi, 1999). In Experiment 3, there was a significant quadratic increase in fruit diameter and weight with application time and a significant linear increase in fruit diameter and weight with rate, both reaching a peak at a rate of 200 $mg.l^{-1}$ BA, at 8 to 10 mm fruitlet size i.e. 11 d.a.f.b. (Table 15). 150 and 200 $mg.l^{-1}$ BA increased fruit firmness relative to the control. A significant linear increase in flesh firmness with application time was observed (Table 15). 150 to 200 $mg.l^{-1}$ BA did not improve fruit firmness on 'Williams Bon Chrétien' (Dussi *et al.,* 2008)

The final fruit size of pears at harvest is determined by both cell division and cell expansion within the fruits (Westwood, 1993; Webster, 2002b). During the early stages of bloom and fruit development, much growth is the result of cell division (Faust; 1989; Westwood, 1993). After fertilization, a period of rapid cell division starts and continues for 7 to 9 weeks in pears (Sterling, 1954; Bain, 1961; Faust, 1989; Westwood, 1993). Early cell division in fruits is normally influenced by cytokinins (Looney, 1993), therefore, applying synthetic cytokinins

during the critical/peak stages of cell division is likely to prolong the phase of mitotic cell division of the fruit (Shargal *et al.,* 2006).

Cell expansion is also active during the main cell division period, but its effect is masked by the simultaneous occurrence of cell division (Bain, 1961; Westwood, 1993). According to Van Staden and Cook (1986), the highest cytokinin levels in developing fruits occur not in early stages of cell division, but during early phases of fruit enlargement. Thus, cytokinins applied during the early stages of cell enlargement could potentially affect both cell division and cell enlargement. Therefore, in Experiment 3, the 11 d.a.f.b. application was more effective in increasing fruit size than the earliest application, 8 d.a.f.b. and the latest application 17 d.a.f.b. (Table 15). Similar observations were made in Israel on 'Spadona' pear, where the synthetic cytokinin, CPPU applied 14 d.a.f.b. was more effective than when applied 7, 21 and 28 d.a.f.b. on improving fruit size (Stern e*t al.,* 2002). Based on the results, 200 $mg.l^{-1}$ BA applied at 8 to 10 mm fruitlet size, i.e. 11 d.a.f.b. is the ideal rate and application time for increasing fruit size of 'Forelle'.

A statistical analysis conducted using number of fruits thinned by hand as a covariate suggested that the increase in fruit diameter and weight associated with BA was a direct effect rather than a secondary effect from thinning (Table 14). This is because in Experiment 3, even when adjusted for the number of fruits that had to be thinned by hand, the treatments still remained significant. This adjustment increased the significance of the treatments (Table 17). BA significantly reduced the number of fruits thinned by hand (Table 12), and significantly increased fruit diameter and weight (Table 15). The covariate (number of fruits that had to be thinned by hand) was statistically significant (Table 14). Therefore, both a reduction in crop load and the direct effect of BA have an important effect on improving fruit size. The number of fruits that had to be thinned by hand as a covariate, had a significant effect on fruit firmness (Table 14), therefore, reduction in crop load has an important effect on improving fruit firmness.

According to Marais (1995), pears weighing less than 140 grams are not commercially acceptable. However, this varies with the target market. North American and Australian consumers prefer bigger fruit, whilst European consumers prefer smaller fruit (Theron, pers. comm; Wertheim, 2000). There were no apparent trends in fruit size distribution relative to

the control in the trials conducted in the 2006/7 season and at Oak Valley in the 2007/8 season (Fig. 1; 2; 3; 4). However, over 50 % of the fruit from each treatment at the Buchuland site in the 2006/7 season were in the > 140 grams category (Fig. 3). BA significantly reduced fruit set at the Buchuland site in the 2006/7 season (Table 4). Similar results were reported by Wertheim (2000) on 'Conference' pear and on 'Early Bon Chrétien' pear in Chapter 2, where 200 $mg.l^{-1}$ reduced fruit set without affecting fruit size or return bloom (on 'Conference') as both were already at acceptable levels.

Less than 50 % of the fruit from all the treatments at Buchuland in the 2007/8 season were in the > 140 grams category. However, a discernable shift in fruit size distribution relative to the control was observed with 100 $mg.l^{-1}$ BA applied at 8 to 10 and 200 $mg.l^{-1}$ BA applied at 8 to 10 or 10 to 12 mm fruit diameter(Fig. 7). The 200 $mg.l^{-1}$ rate was more effective (Fig. 7). Time of application had an effect on fruit size distribution, inducing a somewhat quadratic shift in fruit size distribution (Fig. 7). The 8 to 10 mm average fruit size, i.e. 11 d.a.f.b. application time produced more fruits > 140 grams relative to the 8 and 17 d.a.f.b. application times and the unsprayed control (Fig. 7). This reflects the significant quadratic effect application time had on fruit weight and diameter (Table 15). Therefore, based on the results, application time had a greater effect on fruit size distribution than application rate. The application of BA at 8 to 10 mm average fruit diameter, i.e. 11 d.a.f.b. is the ideal application time for improving fruit size distribution of 'Forelle'.

Fruit quality and seed abortion

The BA applications did not affect fruit shape, seed numbers or percentage calyx-end ribbing at any of the sites (Table 6; 11; 16). 100 to 200 $mg.l^{-1}$ BA had no effect on fruit shape and seed number of 'Williams Bon Chrétien', 'Spadona' and 'Coscia' pears (Stern and Flaishman, 2003; Dussi *et al.*, 2008). Similar observations were made in Chapter 2, where 100 and 150 $mg.l^{-1}$ BA did not affect seed numbers and fruit shape of 'Early Bon Chrétien'. BA did not increase seed number, therefore increments in fruit size were therefore not related to a change in the number of viable seeds. Seeds are a source of endogenous cytokinins (Flaishman *et al.,* 2001; Bangerth, 2004). BA at a rate of 200 $mg.l^{-1}$ impaired red colour formation of apples (Wertheim, 2000). The same BA rate, 200 $mg.l^{-1}$ did not affect skin colour of 'Forelle' pears (Table 11), therefore, unlike with apples, BA does not have a negative effect on red colour

formation of ‘Forelle’ pear.

Return bloom

Chemical thinning, in terms of the thinning agent used as well as the degree of crop load reduction achieved, is likely to have an effect on the amount and quality of flower buds formed in the following season. BA at rates of 100 to 150 mg.l^{-1} at 8 to 12 mm fruit size did not significantly improve return bloom in Experiment 1 (Table 7). The inability of these rates to promote return bloom on ‘Forelle’, can be attributed to the inability of these BA rates to reduce fruit set especially at the La Plaisante sites (Table 3). However, at the La Plaisante site (Orchard 2), the 100 and 150 mg.l^{-1} BA rates increased return bloom by ± 87 to ± 101 % of the control (Table 5). In Experiment 2, the BA sprays slightly improved return bloom relative to the unsprayed control, however this was not statistically significant (Table 10). This was probably because the BA sprays failed to reduce fruit set (Table 8). The 200 mg.l^{-1} BA rate was the most effective treatment, improving return bloom by approximately 40 %. On ‘Conference pear, BA at 200 mg.l^{-1} did not significantly improve return bloom despite significantly reducing fruit set, this was attributed to the parthenocarpic nature of the cultivar (Vilardell *et al.,* 2005). ‘Forelle’ pear is also a parthenocarpic pear cultivar which produces very few (averaging less than 1 well-developed seed per fruit) viable seeds (Table 6; 11; 16) and thus requires GA_3 sprays at bloom to improve fruit set (See Materials and methods). However, in Experiment 3, BA significantly improved return bloom relative to the control (Table 17). The 200 mg.l^{-1} rate was slightly more effective than the 150 mg.l^{-1} rate. Similar observations were made in Chapter 2, where 100 to 200 mg.l^{-1} BA at 8 to 12 mm fruit size significantly improved return bloom of ‘Early Bon Chrétien’ pear trees, in two out of three trials. On‘Clara Frijs’, 100 mg.l^{-1} BA applied as a post-bloom thinning agent improved return bloom (Bertelsen, 2002).

Analysis of covariance with fruit set as a covariate suggested that the increase in return bloom is a result of the direct effect of BA on flower bud formation and the indirect effect of BA via fruit set reduction (Table 17). In Experiment 2, BA did not significantly improve fruit set or return bloom at Oak Valley. However, when return bloom was adjusted for fruit set, the treatments became significant (Table 10). In Experiment 3, when return bloom was adjusted for fruit set and the number of fruits that had to be thinned by hand, the treatments still

remained significant at the Buchuland site in the 2007/8 season. According to Tromp (2000), some thinning compounds may affect flower bud formation directly without any intervention of fruits. However, this adjustment reduced the significance of the treatments (Table 14). BA did not reduce fruit set significantly, whilst it significantly reduced the number of fruits that had to be thinned by hand (Table 12). Fruit set and number of fruits that had to be thinned by hand was statistically significant covariates for return bloom (Table 14). Therefore, both a reduction in crop load and the direct effect of BA have an important effect on improving return bloom. High levels of cytokinins during flower induction are known to increase the number of reproductive buds induced (Wertheim, 1990; Reynolds, 2004).

Conclusion

From the present study with 'Forelle' under conditions in the Western Cape, South Africa, it can be concluded that BA rates below 150 $mg.l^{-1}$ are insufficient to reduce crop load and improve fruit size of 'Forelle' pears. 150 $mg.l^{-1}$ BA using a single or split application and the 200 $mg.l^{-1}$ rate were relatively effective in reducing crop load and improving fruit size of 'Forelle'. There was a significant quadratic increase in BA efficacy with application time, 11 d.a.f.b. applications were more effective than 8 and 17 d.a.f.b. applications in reducing crop load and improving fruit size. Comparing these results to those obtained on 'Early Bon Chrétien' in Chapter 2, higher BA rates were required to reduce crop load and improve fruit size on 'Forelle'. The highest rate of BA (200 $mg.l^{-1}$) was effective. According to Jones *et al.* (2000), thinning strategies for one cultivar cannot be superimposed on another, each cultivar requires separate consideration. Since BA alone has proven to be an unreliable thinner of 'Forelle', further trials may be needed to evaluate combinations of BA and other thinning agents.

References

Bain, J.M. 1961. Some morphological, anatomical, and physiological changes in the pear fruit (*Pyrus communis* var. Williams Bon Chrétien) during development and following harvest. *Aust. J. Bot.* 9: 99 - 123.

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

Bangerth, F. 2004. Internal regulation of fruit growth and abscission. *Acta Hort.* 636: 235 - 248.

Bertelsen, M.G., 2002. Benzyladenine and other thinning agents for pear cv. 'Clara Frijs'. *J. Am. Pomol. Soc.* 56: 149 - 155.

Bound, S.A., Jones, K.M. and Oakford, M.J. 1997a. Post-bloom thinning with 6-benzyladenine. *Acta Hort.* 463: 493 - 499.

Bound, S.A., Jones K.M. and Oakford, M.J. 1997b. Integrating cytolin into a chemical thinning program for red 'Delicious' apple. *Austr. Jour. Exp. Agric.* 37: 113 - 138.

Bound, S.A. and Mitchell, L. 2002. A new post-bloom thinning agent for 'Packham's Triumph' pear. *Acta Hort.* 596: 793 - 796.

Bubán, T. 2000. The use of benzyladenine in orchard fruit growing: a mini review. *Plant Growth Regul.* 32: 381 - 390.

Bubán, T. and Lakatos, T. 2000. Contributions to the efficacy of benzyladenine as a fruit thinning agent for apple cultivars. *Acta Hort*. 514: 59 - 67.

Byers, R.E., Carbaugh, D.H. and Presley, C.N. 1990. The influence of bloom thinning and GA_3 sprays on flower bud numbers and distribution in peach trees. *J. Am. Soc. Hort. Sci.* 65: 143 - 150.

Dennis, F.G. 2000. The history of fruit thinning. *Plant Growth Regul.* 31: 1 - 16.

Dussi, M.C., Giardina G., Reeb, P. and Gastiazoro, J. 2008. Thinning programs in pears cv. Williams. *Acta Hort* (*accepted for publication*).

Faust, M. 1989. Physiology of Temperate Zone Fruit Trees. Wiley, New York, p. 338.

Flaishman, M.A., Shargal, A. and Stern, R.A. 2001. The synthetic cytokinin CPPU increases fruit size and yield of 'Spadona' and 'Coscia' pear (*Pyrus communis* L.). *J. Hort. Sci. Biotech.* 76: 145 - 149.

Greene, D.W. and Autio, W.R. 1989. Evaluation of benzyladenine as a chemical thinner on 'McIntosh' apples. *J. Am. Soc. Hort. Sci.* 114: 68 - 73.

Huysamer, M. 1997. The challenge of bi-coloured pear production. *Proc. Cape. Pom. Ass. Tech. Symp.* Cape Town. 168 - 173.

Jackson, J.E. 2003. Biology of apples and pears. Cambridge University Press.

Jones, K.M., Bound, S.A., Oakford M.J. and Gillard, P. 2000. Modelling thinning of pome fruits. *Plant Growth Regul.* 31: 75 - 84.

Looney, N.E. 1993. Improving fruit size, appearance and other aspects of fruit crop 'quality' with plant bioregulant chemicals. *Acta Hort.* 329: 120 - 127.

Marais, G.F. 1995. Optimisation of the economic biomass production of Forelle pear (*Pyrus communis* L. rosaceae) on seedling rootstock. MScAgric thesis. University of Stellenbosch.

Marini, R. 1998. Experience with thinning: What factors contribute to contradicting results? *HortScience* 33: 553 (abstr).

Reynolds, L.P. 2004. Reproductive bud development in pears. MScAgric thesis. University of Stellenbosch.

Shargal, A., Golobovich, S., Flaishman, M.A., Shlizerman, L.A., Stern, R.A., Grafi, G., Lev-Yadun, S. and Yablovich, Z. 2006. Synthetic cytokinins extend the phase of division of parenchyma cells in developing pear (*Pyrus communis* L.) fruits. *J. Hort. Sci. Biotech.* 81: 915 - 920.

Sterling, C.1954. Sclereid development and the texture of 'Bartlett' pears. *J. Food Sci.* 19: 433 - 443.

Stern, R.A and Flaishman, M.A. 2003. Benzyladenine effects on fruit size, fruit thinning and return yield of 'Spadona' and 'Coscia' pear. *Scientia Hort.* 98: 499 - 504.

Stern, R.A., Shargal, A and Flaishman, M.A. 2002. Effects of the synthetic cytokinin CPPU on fruit size and yield of 'Spadona' pear (Pyrus communis L.). *Acta Hort.* 596: 797 - 801.

Stopar, M., Black, B.L. and Bukovac, M.J. 1997. The effect of NAA and BA on carbon dioxide assimilation by shoot leaves of spur-type 'Delicious' and 'Empire' apple trees. *J. Am. Soc. Hort. Sci.* 122: 837 - 840.

Theron, K.I., Le Grange, M., Smit, M., Reynolds, S. and Jacobs, G. 2002. Controlling vigour and colour development in the bi-coloured pear cultivar 'Rosemarie'. *Acta Hort.* 596: 753 - 756.

Tromp, J. 2000. Flower-bud formation in pome fruits as affected by fruit thinning. *Plant Growth Regul*. 31: 27 - 34.

Van Staden, J. and Cook, E.L. 1986. Cytokinins and fruit production. *Acta Hort.* 179: 73 - 82.

Vilardell, P., Carbó, J., Casals, M., Bonany, J., Asín, L., Dalmau, R., 2005. Effect of 6-BA and NAA as thinning agents of 'Conference' pear. *Acta Hort.* 671: 119 - 124.

Webster, A.D. 2002a. Current approved thinning strategies for apples and pears and recent thinning research in Europe. *Compact Fruit Tree* 35: 73 - 76.

Webster, A.D. 2002b. Factors influencing the flower, fruit set and fruit growth of European pears. *Acta Hort.* 596: 699 - 709.

Wertheim, S.J. 1990. De Peer. Proefstation voor de Fruittetlt, Wilhemibnadorp. pp 88 -94.

Wertheim, S.J. 2000. Developments in the chemical thinning of apple and pear. *Plant Growth Regul.* 31: 85 - 100.

Westwood, M.N. 1993. Temperate-zone pomology: physiology and culture (3rd ed.), Timber Press. Portland, Oregon. pp. 210 - 215.

Williams, M.W. 1994. Factors influencing chemical thinning and update on new chemical thinning agents. *Compact Fruit Tree* 27: 115 - 122.

Williams, K.M. and Fallahi, E. 1999. The effects of exogenous bioregulators and environment on regular cropping of apple. *HortTech*. 9: 317 - 515.

Yuan, R. and Greene, D.W. 2000. Benzyladenine as chemical thinner for 'McIntosh' apples. I. Fruit thinning effects and associated relationships with photosynthesis, assimilate translocation, and non-structural carbohydrates. *J. Amer. Soc. Hort. Sci*. 125: 169 - 176.

3. Tables

Table 1. Orchard details of 'Forelle' trials

	Site				
	La Plaisante 2006/7 (Orchard 1)	La Plaisante 2006/7 (Orchard 2)	Buchuland 2006/7	Oak Valley 2007/8	Buchuland 2007/8
Year planted	1993	1993	1995	1995	1995
Rootstocks	BP3	BP3	BP3	BP1	BP3
Spacing	4.5 x 1.5 m	4.5 x 1.5 m	4.5 x 1.5 m	4.5 x 1.5 m	4.5 x 1.5 m
Training system	Central leader	Central leader	Central leader	Central leader	Central leader
Cross pollinators	'Early Bon Chrétien'	'Early Bon Chrétien'	'Kieffer'	'Abate Fetel'	'Kieffer'
Yield 2003/4	36 ton/ha	39 ton/ha	-		
Yield 2004/5	32 ton/ha	39 ton/ha	43 ton/ha	28 ton/ha	43 ton/ha
Yield 2005/6	31 ton/ha	33 ton/ha	36 ton/ha	37 ton/ha	36 ton/ha
Yield 2006/7	-	-	-	27 ton/ha	41 ton/ha
Full bloom	26 September 2006	26 September 2006	14 September 2006	23 September 2007	23 September 2007
Hand thinning	1 November 2006	1 November 2006	24 September 2006	31 October 2007	29 October 2007
Harvest	5 March 2007	5 March 2007	5 March 2007	4 March 2008	10 March 2008

Table 2. Spray information

	Site				
BA Spay details	La Plaisante 2006/7 (Orchard 1)	La Plaisante 2006/7 (Orchard 1)	Buchuland 2006/7	Oak Valley 2007/8	Buchuland 2007/8
Date 1	14 October 2006	14 October 2006	4 October 2006	15 October 2007	1 October 2007
Temperature °C	19	19	13.5	16.0	18.0
Relative Humidity (%)	70	70	55.0	65	59
Date 2				25 October 2007	4 October 2007
Temperature °C				16.5	13.0
Relative Humidity (%)				52	75
Date 3				1 November 2007	10 October 2007
Temperature °C				18.0	16.5
Relative Humidity (%)				80	54
Date 4				8 November 2007	
Temperature °C				18.5	
Relative Humidity (%)				62	

Table 3. Effect of different rates of 6-benzyladenine (BA) applied at 8 to 12 mm fruit diameter on fruit set and the number of fruits thinned by hand on 'Forelle pear trees in the 2006/7 season.

Treatment	Average fruit set per cluster on two tagged branches*	Average number of fruits thinned by hand per tree
La Plaisante (Orchard 1)		
Control	1.220 ns	175.6 ns
100 mg.l^{-1} BA	1.070 ns	193.6 ns
125 mg.l^{-1} BA	0.860 ns	224.9 ns
150 mg.l^{-1} BA	0.930 ns	168.0 ns
Significance level	*0.0968*	*0.0981*
La Plaisante (Orchard 2)		
Control	1.053 ns	154.8 ns
100 mg.l^{-1} BA	0.996 ns	147.6 ns
125 mg.l^{-1} BA	0.914 ns	121.8 ns
150 mg.l^{-1} BA	1.035 ns	139.7 ns
Significance level	*0.7987*	*0.3389*
Buchuland		
Control	0.930 a	290.0 a
100 mg.l^{-1} BA	0.760 ab	278.0 a
125 mg.l^{-1} BA	0.600 b	285.0 a
150 mg.l^{-1} BA	0.600 b	216.0 b
Significance level	*0.0067*	*0.0321*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Number of fruits after natural fruit drop /number of flower clusters at bloom.

Table 4. Effect of different rates of 6-benzyladenine (BA) applied at 8 to 12 mm fruit diameter on yield of 'Forelle' pear trees in the 2006/7 season.

Treatment	Yield efficiency (kg/cm trunk circumference)	Estimated yield (ton/ha)
La Plaisante (Orchard 1)		
Control	0.708 ns	45.33
100 mg.l^{-1} BA	0.802 ns	49.40
125 mg.l^{-1} BA	0.761 ns	51.29
150 mg.l^{-1} BA	0.660 ns	43.08
Significance level	*0.2385*	
La Plaisante (Orchard 2)		
Control	0.490 ns	35.70
100 mg.l^{-1} BA	0.580 ns	39.31
125 mg.l^{-1} BA	0.520 ns	35.51
150 mg.l^{-1} BA	0.540 ns	37.67
Significance level	*0.3678*	
Buchuland		
Control	0.585 ns	43.69
100 mg.l^{-1} BA	0.615 ns	43.76
125 mg.l^{-1} BA	0.579 ns	43.22
150 mg.l^{-1} BA	0.538 ns	39.63
Significance level	*0.3916*	

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 5. Effect of different rates of 6-benzyladenine (BA) applied at 8 to 12 mm fruit diameter on fruit size of 'Forelle' in the 2006/7 season.

Treatment	Average fruit diameter (mm)	Average fruit length (mm)	Average fruit weight (g)
La Plaisante (Orchard 1)			
Control	64.23 ns	78.65 ns	152.68 ns
100 mg.l^{-1} BA	64.83 ns	78.22 ns	155.30 ns
125 mg.l^{-1} BA	65.72 ns	79.90 ns	162.44 ns
150 mg.l^{-1} BA	64.46 ns	78.56 ns	153.08 ns
Significance level	*0.4005*	*0.6359*	*0.3770*
La Plaisante (Orchard 2)			
Control	60.99 ns	76.25 ns	132.54 ns
100 mg.l^{-1} BA	63.44 ns	80.30 ns	153.27 ns
125 mg.l^{-1} BA	63.00 ns	78.43 ns	148.50 ns
150 mg.l^{-1} BA	62.02 ns	77.83 ns	140.92 ns
Significance level	*0.1766*	*0.0850*	*0.0754*
Buchuland			
Control	61.60 ns	82.60 ns	143.30 ns
100 mg.l^{-1} BA	63.00 ns	83.90 ns	152.50 ns
125 mg.l^{-1} BA	62.30 ns	83.20 ns	146.70 ns
150 mg.l^{-1} BA	61.80 ns	83.10 ns	144.80 ns
Significance level	*0.2509*	*0.6374*	*0.1891*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 6. Effect of different rates of 6-benzyladenine (BA) applied at 8 to 12 mm fruit diameter on seed abortion and calyx-end ribbing of 'Forelle' pear trees in the 2006/7 season.

Treatment	Number of well - developed seeds per fruit	Number of aborted seeds per fruit	% Fruit with calyx-end ribbing
La Plaisante (Orchard 1)			
Control	0.43 ns	9.28 ns	40.89 ns
100 mg.l^{-1} BA	0.42 ns	9.26 ns	45.78 ns
125 mg.l^{-1} BA	0.55 ns	9.15 ns	42.67 ns
150 mg.l^{-1} BA	0.68 ns	9.08 ns	47.11 ns
Significance level	*0.1885*	*0.5537*	*0.6730*
La Plaisante (Orchard 2)			
Control	0.11 ns	9.59 ns	38.00 ns
100 mg.l^{-1} BA	0.31 ns	9.25 ns	40.00 ns
125 mg.l^{-1} BA	0.33 ns	8.92 ns	34.40 ns
150 mg.l^{-1} BA	0.25 ns	9.11 ns	36.80 ns
Significance level	*0.2112*	*0.2949*	*0.9677*
Buchuland			
Control	0.16 ns	9.50 ns	38.00 ns
100 mg.l^{-1} BA	0.26 ns	9.40 ns	29.60 ns
125 mg.l^{-1} BA	0.19 ns	9.44 ns	38.00 ns
150 mg.l^{-1} BA	0.26 ns	9.15 ns	26.00 ns
Significance level	*0.6000*	*0.1128*	*0.2745*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 7. Effect of different rates of 6-benzyladenine (BA) applied at 8 to 12 mm fruit diameter on return bloom of 'Forelle' pear trees in the 2006/7 season.

Treatment	Percentage return bloom on two tagged branches*
La Plaisante (Orchard 1)	
Control	18.7 ns
100 mg.l^{-1} BA	17.6 ns
125 mg.l^{-1} BA	20.2 ns
150 mg.l^{-1} BA	18.7 ns
Significance level	*0.9531*
La Plaisante (Orchard 2)	
Control	8.9 ns
100 mg.l^{-1} BA	16.6 ns
125 mg.l^{-1} BA	17.9 ns
150 mg.l^{-1} BA	16.3 ns
Significance level	*0.2599*
Buchuland	
Control	14.3 ns
100 mg.l^{-1} BA	15.6 ns
125 mg.l^{-1} BA	15.4 ns
150 mg.l^{-1} BA	16.6 ns
Significance level	*0.6739*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Return Bloom (reproductive buds × 100/reproductive + vegetative buds).

Table 8. Effect of different 6-benzyladenine (BA) rates and application methods on fruit set and hand thinning requirements of 'Forelle' pear at Oak Valley 2007/8 season.

Treatment	Average fruit set per cluster on two tagged branches*	Average number of fruit thinned by hand per tree
Control	1.58 ns	90.00 ns
150 mg.l^{-1} BA	1.26 ns	90.67 ns
200 mg.l^{-1} BA	1.08 ns	86.78 ns
3* 50 mg.l^{-1} BA	1.22 ns	83.11 ns
Significance level	*0.1623*	*0.9927*
LSD	0.45	57.95

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Number of fruits after natural fruit drop /number of flower clusters at bloom.

Table 9. Effect of different 6-benzyladenine (BA) rates and application methods on yield of 'Forelle' pear at Oak Valley 2007/8 season.

Treatment	Yield efficiency (kg/cm trunk circumference)	Estimated yield (ton/ha)
Control	0.65 ab	21.50
150 mg.l^{-1} BA	0.67 ab	23.85
200 mg.l^{-1} BA	0.59 b	19.53
3* 50 mg.l^{-1} BA	0.75 a	25.53
Significance level	*0.0399*	-
LSD	0.11	-
Covariate analysis		
Fruit set	*0.0078*	-
Treatment	*0.0155*	-
Hand thinning	*0.4164*	-
Treatment	*0.0463*	-

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 10. Effect of different 6-benzyladenine (BA) rates and application methods on fruit size and firmness at harvest and return bloom the following year of 'Forelle' pear at Oak Valley 2007/8 season.

Treatment	Average fruit diameter (mm)	Average fruit length (mm)	Average fruit weight (g)	Average fruit firmness (kg)	Percentage return bloom on two tagged branches*
Control	54.96 b	74.36 b	103.33 ns	6.51 ns	16.00 ns
150 mg.l^{-1} BA	56.73 a	76.65 ab	112.90 ns	6.59 ns	21.22 ns
200 mg.l^{-1} BA	57.33 a	78.60 a	115.88 ns	6.50 ns	22.44 ns
3* 50 mg.l^{-1} BA	57.10 a	77.25 ab	112.24 ns	6.48 ns	19.33 ns
Significance level	*0.0397*	*0.0463*	*0.0966*	*0.6611*	*0.1386*
LSD	1.74	2.94	10.24	0.19	5.77
Covariate analysis					
Fruit set	*0.5076*	*0.0716*	*0.5348*	*0.2431*	*0.6916*
Treatment	*0.0380*	*0.1282*	*0.0809*	*0.6060*	*0.0304*
Hand thinning	*0.7472*	*0.4547*	*0.6622*	*0.1866*	*0.2035*
Treatment	*0.0468*	*0.0537*	*0.1084*	*0.6857*	*0.1518*

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* Return Bloom (reproductive buds × 100/reproductive + vegetative buds).

Table 11. Effect of different 6-benzyladenine (BA) rates and application methods on blush, seed abortion, malformation and calyx-end ribbing of 'Forelle' pear at Oak Valley 2007/8 season.

Treatment	Blush amount *	Number of well - developed seeds per fruit	Number of aborted seeds per fruit	% Malformed fruit	% Fruit with calyx-end ribbing
Control	2.80 ns	0.28 ns	9.60 ns	32.44 ns	49.33 ns
150 mg.l^{-1} BA	2.37 ns	0.40 ns	9.51 ns	23.56 ns	47.56 ns
200 mg.l^{-1} BA	2.44 ns	0.29 ns	9.68 ns	28.44 ns	44.89 ns
3* 50 mg.l^{-1} BA	2.32 ns	0.31 ns	9.62 ns	25.78 ns	47.11 ns
Significance level	*0.2539*	*0.6048*	*0.4532*	*0.4968*	*0.8877*
LSD	0.53	0.20	0.22	12.34	11.61

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

* The amount of blush was evaluated on a scale of 1 to 6 (1 = most blush; 6 = least blush)

Table 12. Effect of 6-benzyladenine (BA) applications on fruit set and the number of fruit thinned by hand per tree of 'Forelle' pear at Buchuland 2007/8 season.

Treatment	Average fruit set per cluster on two tagged branches*	Average number of fruit thinned by hand per tree
Control	1.71	291.50
Rate:		
150 mg.l^{-1} BA	1.59	183.67
200 mg.l^{-1} BA	1.44	158.17
Timing:		
6-8 mm fruit size	1.48	229.55
8-10 mm fruit size	1.41	146.75
10-12 mm fruit size	1.66	136.45
Significance level	*0.0995*	*<.0001*
Contrast		
Rate	*0.1367*	*0.1258*
Time Lin	*0.1279*	*<.0001*
Time Quad	*0.0942*	*0.0419*
Rate*Time Lin	*0.3931*	*0.8975*
Rate*Time Quad	*0.4570*	*0.8908*

*Number of fruits after natural fruit drop /number of flower clusters at bloom.

Table 13. Effect of 6-benzyladenine (BA) applications on yield of 'Forelle' pear at Buchuland 2007/8 season.

Treatment	Yield efficiency (kg/cm trunk circumference)	Estimated yield (ton/ha)
Control	0.76	39.47
Rate:		
150 mg.l^{-1} BA	0.67	33.94
200 mg.l^{-1} BA	0.61	31.32
Timing:		
6-8 mm fruit size	0.70	35.60
8-10 mm fruit size	0.69	35.35
10-12 mm fruit size	0.54	27.00
Significance level	*0.0002*	-
Contrasts		
Rate	*0.0954*	-
Time Lin	*0.0001*	-
Time Quad	*0.0450*	-
Rate*Time Lin	*0.3799*	-
Rate*Time Lin	*0.7737*	-

Table 14. Analysis of covariance of yield effeciency, fruit diameter, weight and firmness at harvest, and return bloom the following season as a function of fruit set and number of fruits thinned by hand (covariates) at Ceres, Buchuland in the 2007/8 season.

Effects tested	Yield efficiency (kg/cm)	Fruit diameter (mm)	Fruit length (mm)	Fruit weight (g)	Fruit firmness (kg)	Return bloom (%)
Treatment	*0.0002*	*0.0016*	*0.0146*	*0.0004*	*0.1263*	*0.0003*
Fruit set*	*0.2484*	*0.8082*	*0.6362*	*0.3242*	*0.8142*	*0.0048*
Treatment	*0.0002*	*0.0013*	*0.0151*	*0.0004*	*0.1366*	*0.0010*
Hand thinning*	*<.0001*	*0.0016*	*0.0016*	*<.0001*	*0.0012*	*0.0010*
Treatment	*0.0151*	*0.0004*	*0.0320*	*0.0002*	*0.4596*	*0.0022*

* Fruit set on two tagged branches or number of fruit removed by hand thinning used as covariates.

Table 15. Effect of 6-benzyladenine (BA) applications on fruit size and firmness of 'Forelle' pear at Buchuland 2007/8 season.

Treatment	Average fruit diameter (mm)	Average fruit length (mm)	Average fruit weight (g)	Average fruit firmness (kg)
Control	59.98	76.75	135.94	6.37
Rate:				
150 mg.l^{-1} BA	60.00	77.93	136.17	6.42
200 mg.l^{-1} BA	61.11	79.90	143.62	6.50
Timing:				
6-8 mm fruit size	62.26	78.01	135.89	6.41
8-10 mm fruit size	61.36	79.55	145.33	6.42
10-12 mm fruit size	60.00	79.19	138.48	6.56
Significance level	*0.0016*	*0.0146*	*0.0004*	*0.1263*
Contrasts				
Rate	*0.0039*	*0.0115*	*0.0011*	*0.1804*
Time Lin	*0.8239*	*0.2057*	*0.3316*	*0.0231*
Time Quad	*0.0004*	*0.2366*	*0.0008*	*0.2419*
Rate*Time Lin	*0.6433*	*0.1658*	*0.3505*	*0.9398*
Rate*Time Quad	*0.7706*	*0.3116*	*0.2709*	*0.5654*

Table 16. Effect of 6-benzyladenine (BA) applications on fruit malformation, seed abortion and calyx-end ribbing of 'Forelle' pear at Buchuland 2007/8 season.

Treatment	% Malformed fruit	Number of well developed seeds per fruit	Number of aborted seeds per fruit	% Fruit with calyx-end ribbing
Control	18.80	0.21	9.71	53.60
Rate:				
150 mg.l^{-1} BA	16.53	0.22	9.58	53.47
200 mg.l^{-1} BA	14.80	0.46	9.59	54.93
Timing:				
6-8 mm fruit size	15.00	0.32	9.61	56.4
8-10 mm fruit size	15.40	0.32	9.46	53.4
10-12 mm fruit size	16.60	0.40	9.70	52.8
Significance level	*0.4947*	*0.4355*	*0.3167*	*0.6137*
Contrasts				
Rate	*0.3837*	*0.2564*	*0.8639*	*0.4901*
Time Lin	*0.5108*	*0.1465*	*0.5103*	*0.1695*
Time Quad	*0.8492*	*0.3889*	*0.0973*	*0.5942*
Rate*Time Lin	*0.5108*	*0.4886*	*0.2573*	*0.2211*
Rate*Time Quad	*0.1322*	*0.3507*	*0.1751*	*0.6569*

Table 17. Effect of 6-benzyladenine (BA) applications on return bloom of 'Forelle' pear at Buchuland 2007/8 season.

Treatment	Percentage return bloom on two tagged branches*
Control	27.89
Rate:	
150 mg.l^{-1} BA	37.78
200 mg.l^{-1} BA	38.49
Timing:	
6-8 mm fruit size	39.31
8-10 mm fruit size	38.81
10-12 mm fruit size	36.29
Significance level	*0.0003*
Contrasts	
Rate	*0.6444*
Time Lin	*0.1133*
Time Quad	*0.5383*
Rate*Time Lin	*0.6871*
Rate*Time Quad	*0.1485*

* Return Bloom (reproductive buds × 100/reproductive + vegetative buds).

Figures

Climatic data

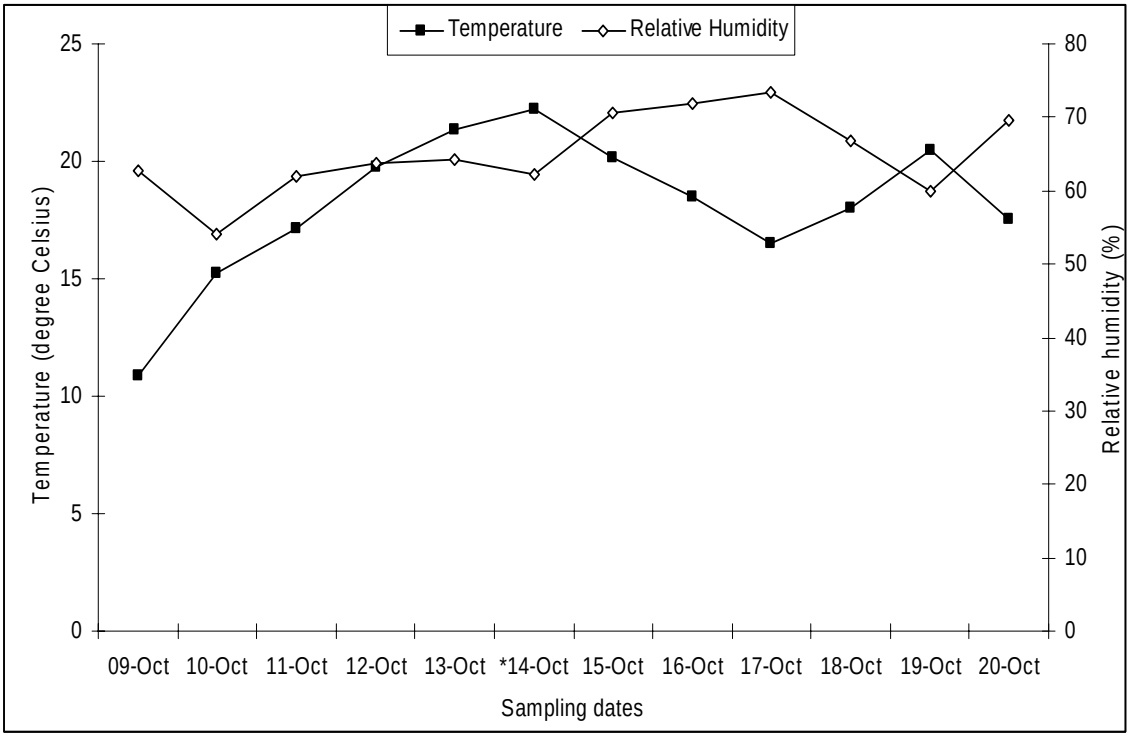

Fig. 1. Mean daily temperature and relative humidity from 9 to 20 October 2006 at La Plaisante Estate, Wolseley.

* Spray date.

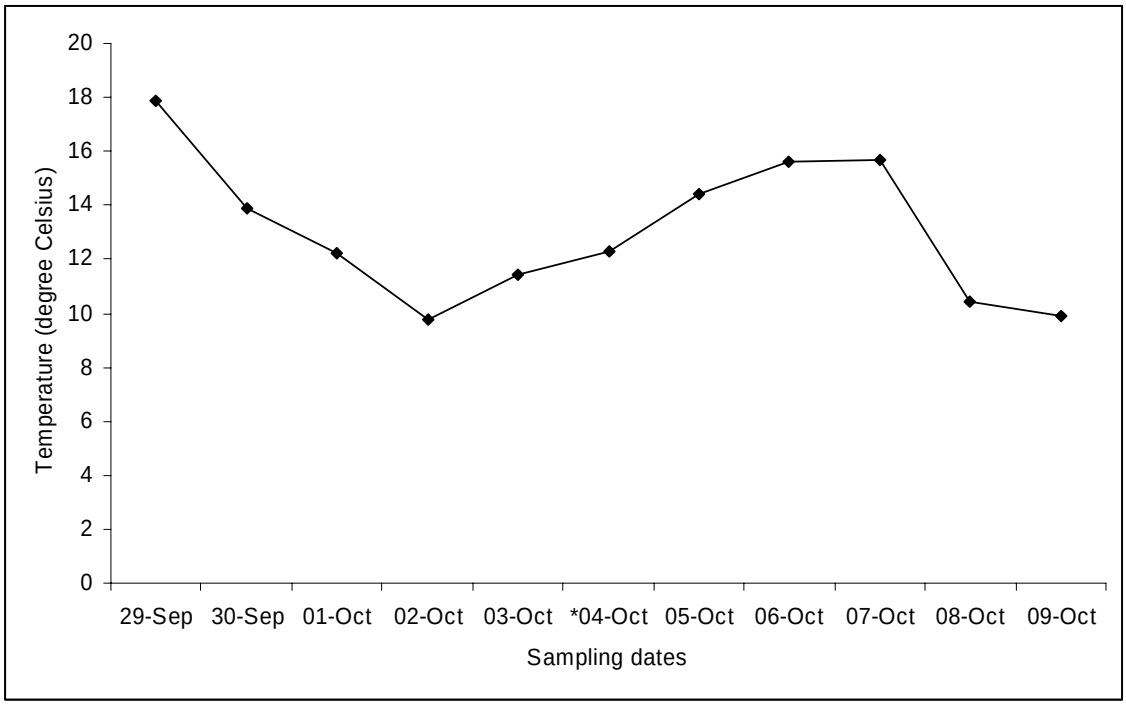

Fig. 2. Mean daily temperatures from 29 September to 9 October 2006 at Buchuland farm, Ceres. * Spray date.

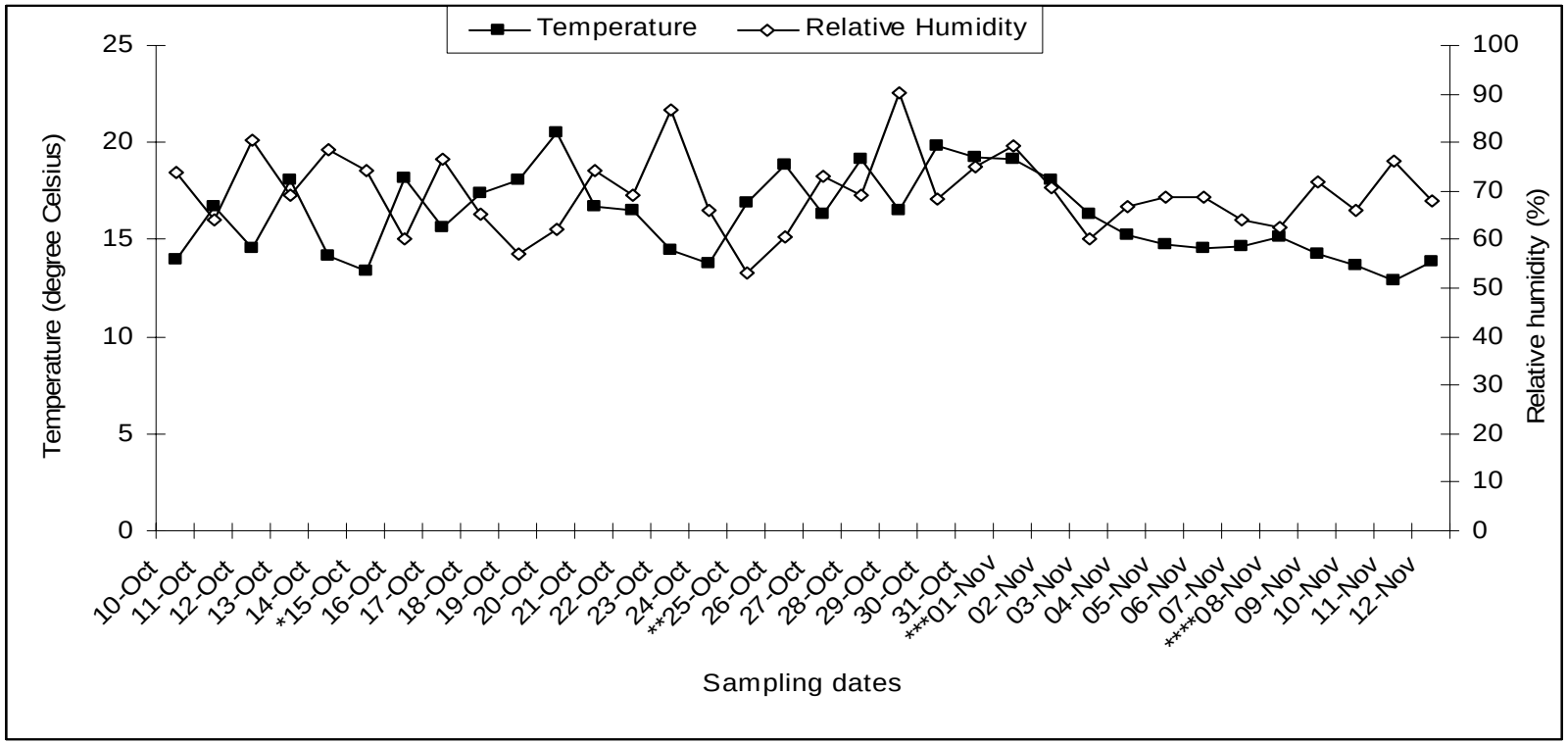

Fig. 3. Mean daily temperature and relative humidity from 26 September to 16 October 2007 at Oak Valley Estate, Grabouw.

*First spray date (150 and 200 mg.l^{-1} treatments).

**Second spray date (1st split application, 50 mg.l^{-1}).

***Third spray date (2nd split application, 50 mg.l^{-1}).

**** Forth spray date (3rd split application, 50 mg.l^{-1}).

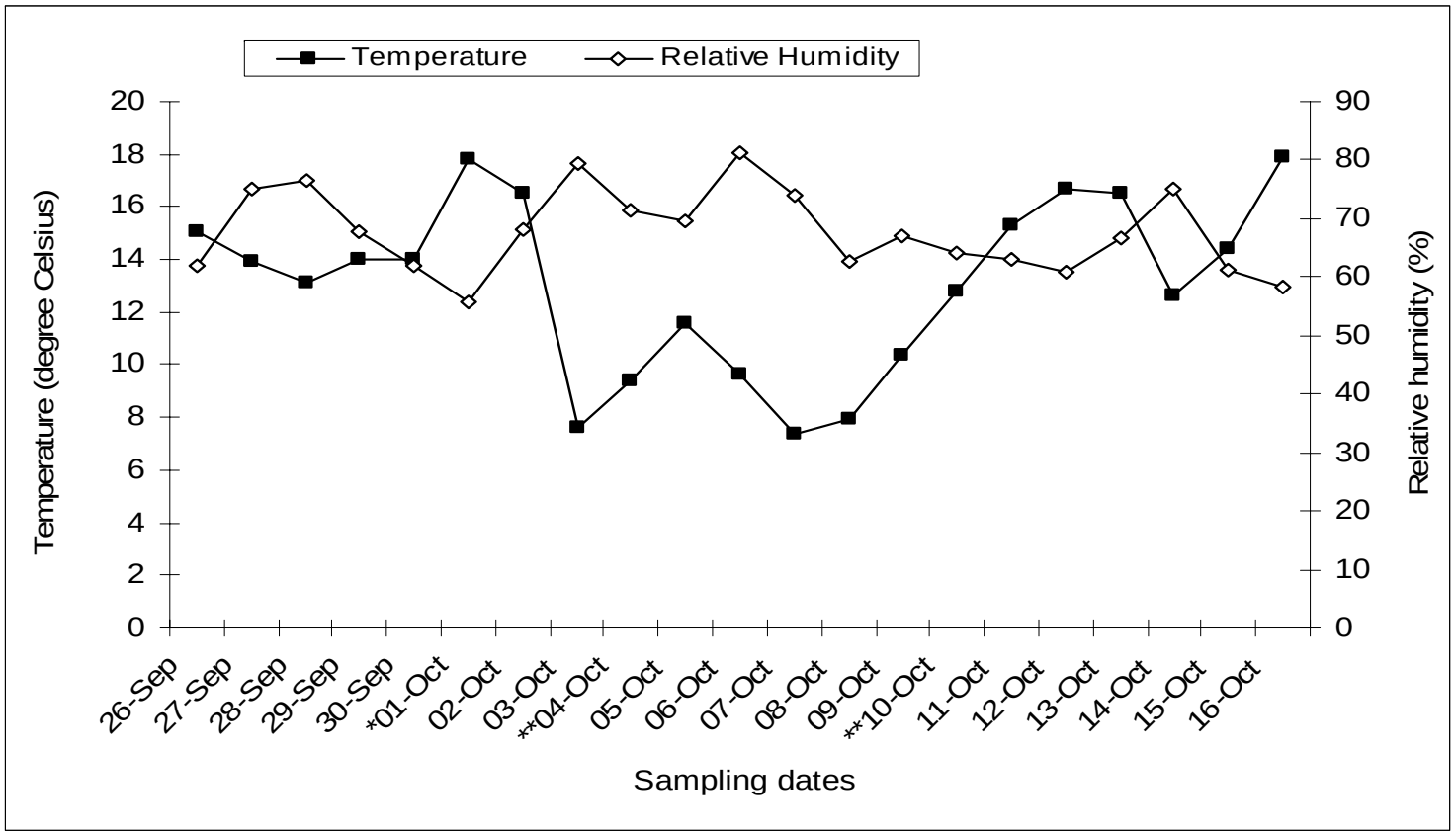

Fig. 4. Mean daily temperature and humidity from 26 September to 16 October 2007 at Buchuland farm, Ceres.

*First spray date (6 to 8 mm fruitlet size i.e. 8 d.a.f.b.)

**Second spray date (8 to 10 mm fruitlet size i.e. 11 d.a.f.b.)

***Third spray date (10 to 12 mm fruitlet size i.e. 17 d.a.f.b.)

Fruit size distribution

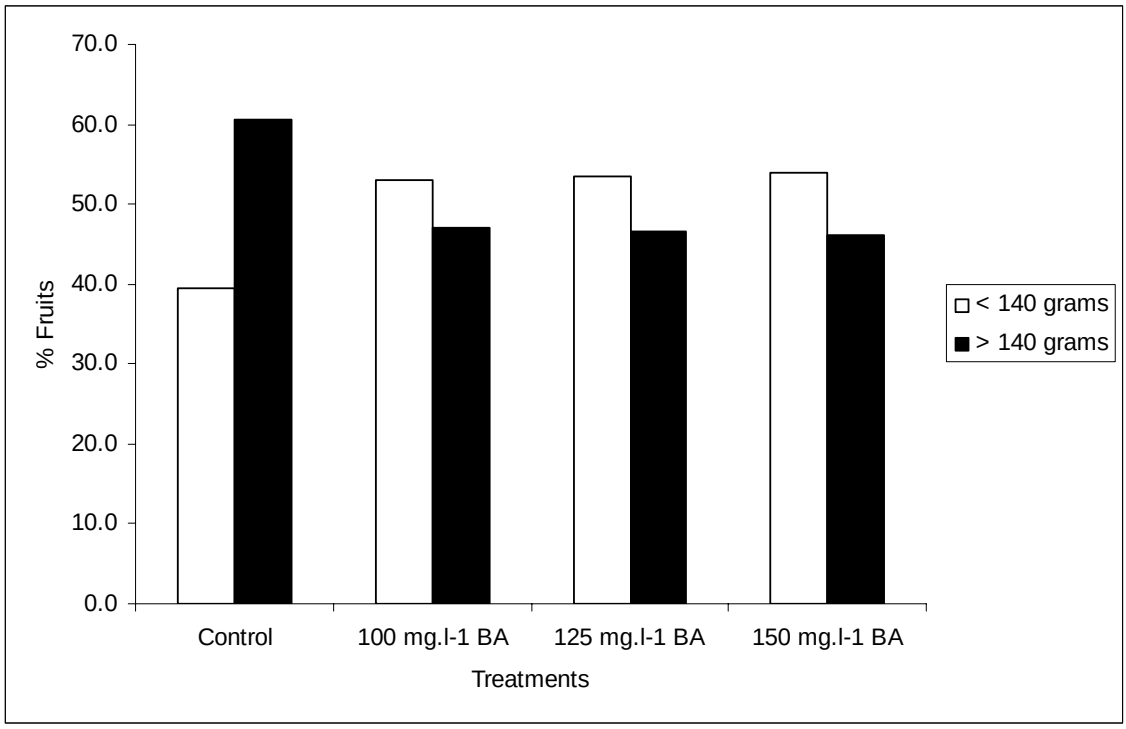

Fig. 5. Effect of different BA rates on fruit size distribution of 'Forelle' at La Plaisante Estate (Orchard 1), Wolseley 2006/7 season.

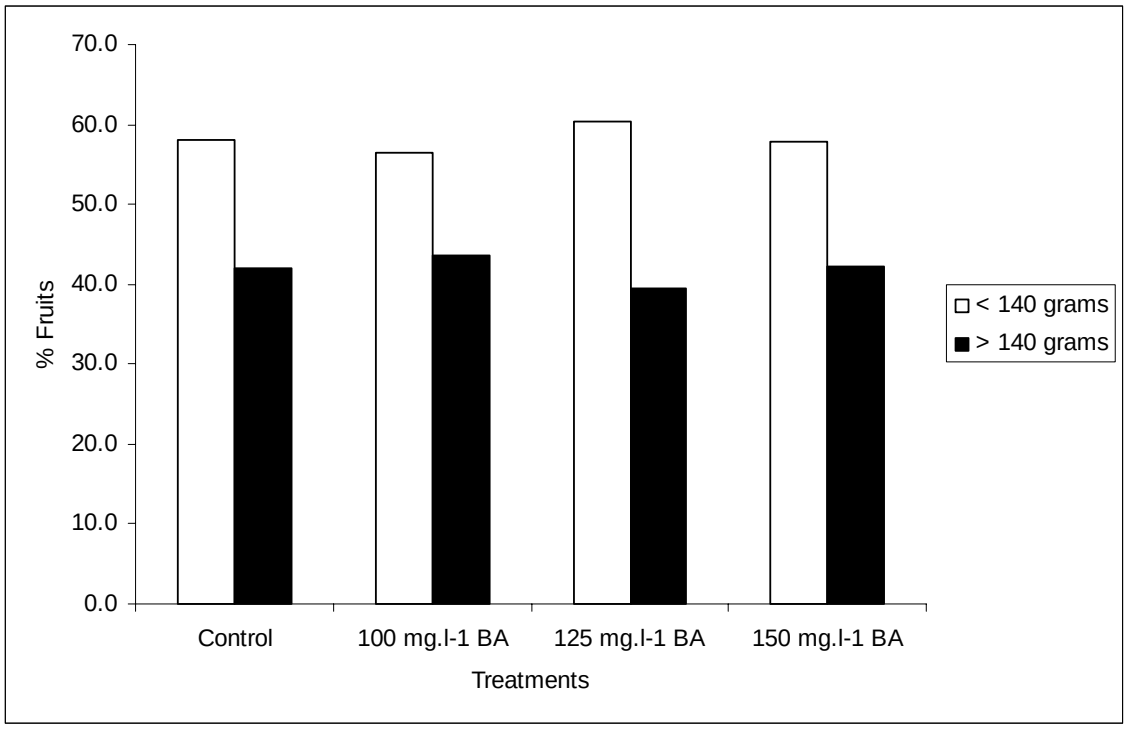

Fig. 6. Effect of different BA rates on fruit size distribution of 'Forelle' at La Plaisante Estate (Orchard 2), Wolseley 2006/7 season.

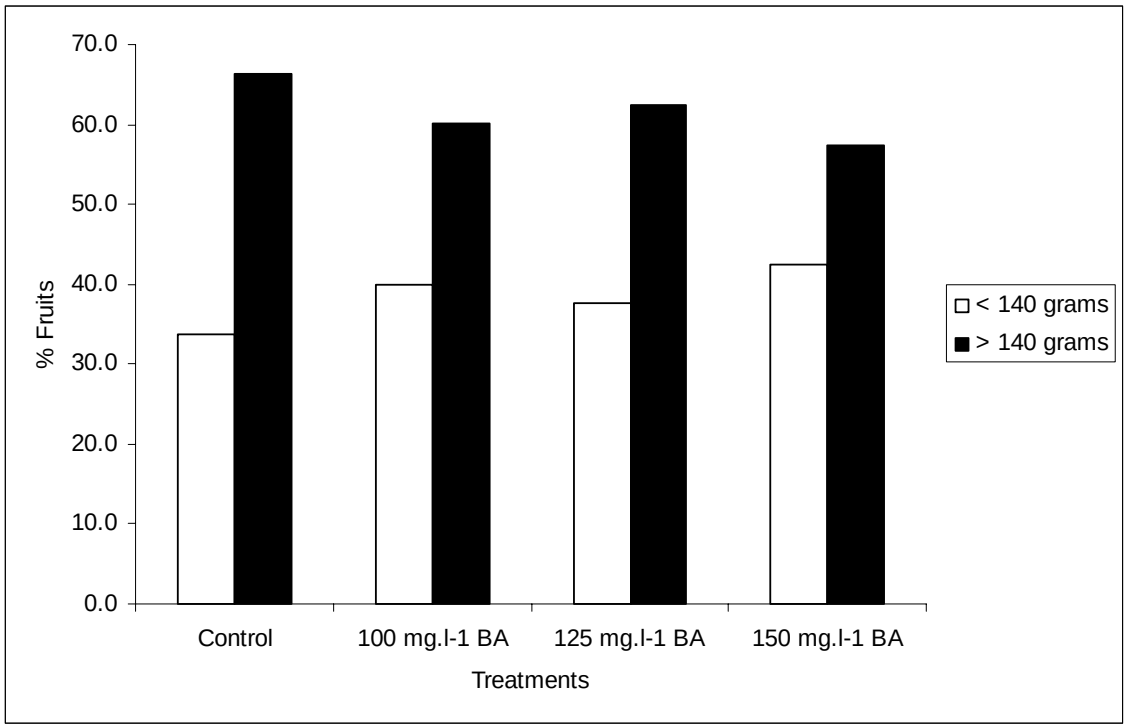

Fig. 7. Effect of different BA rates on fruit size distribution of 'Forelle' at Buchuland, Ceres 2006/7 season.

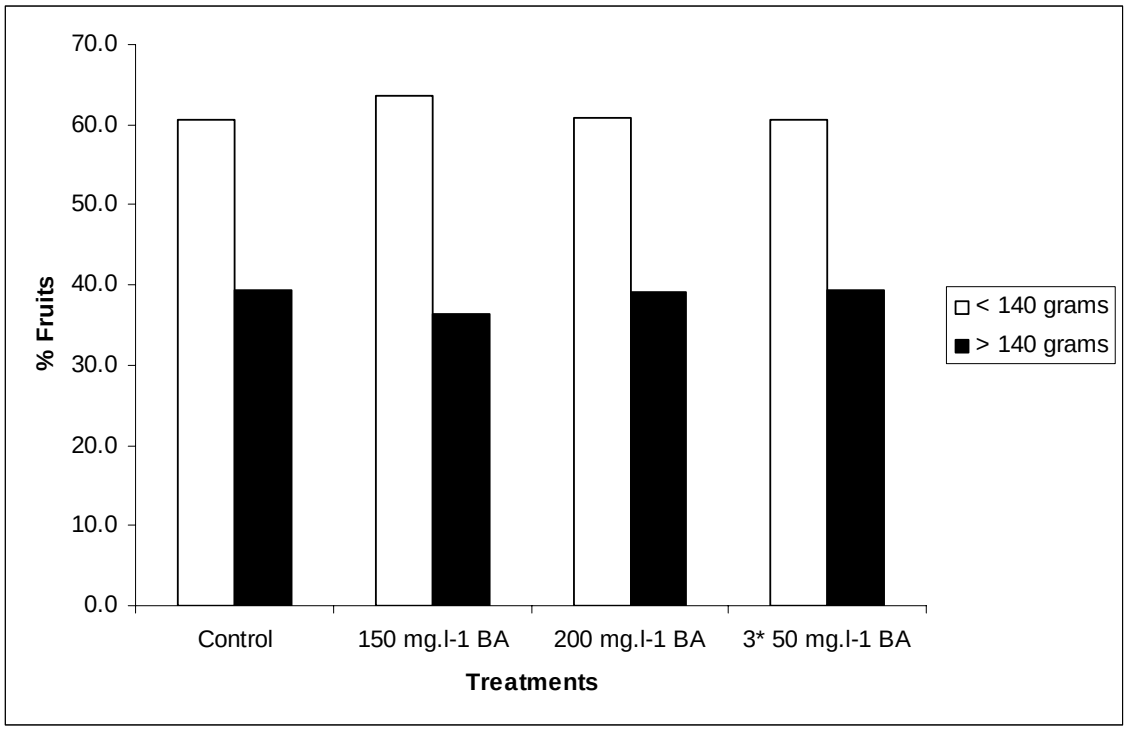

Fig. 8. Effect of different BA rates and application methods on fruit size distribution in 'Forelle' fruits at Oak Valley, Grabouw 2007/8 season.

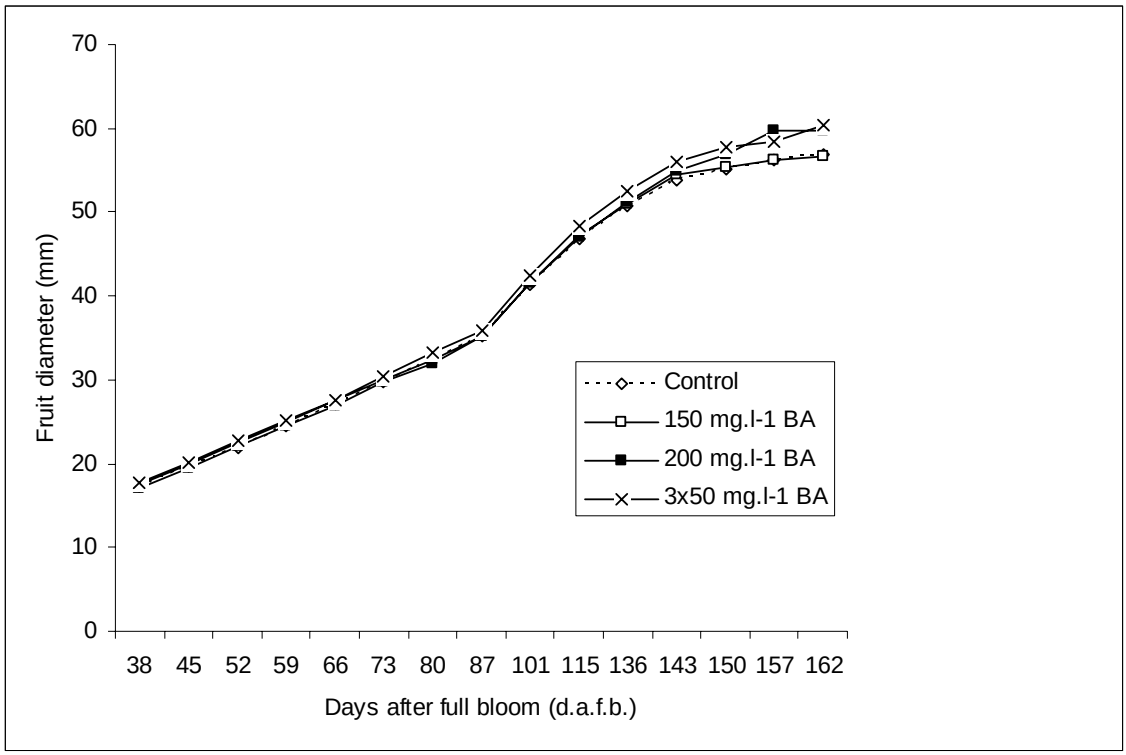

Fig. 9. Changes in 'Forelle' fruit diameter plotted on a time-from-bloom basis, as affected by BA sprays at Oak Valley 2007/8 season.

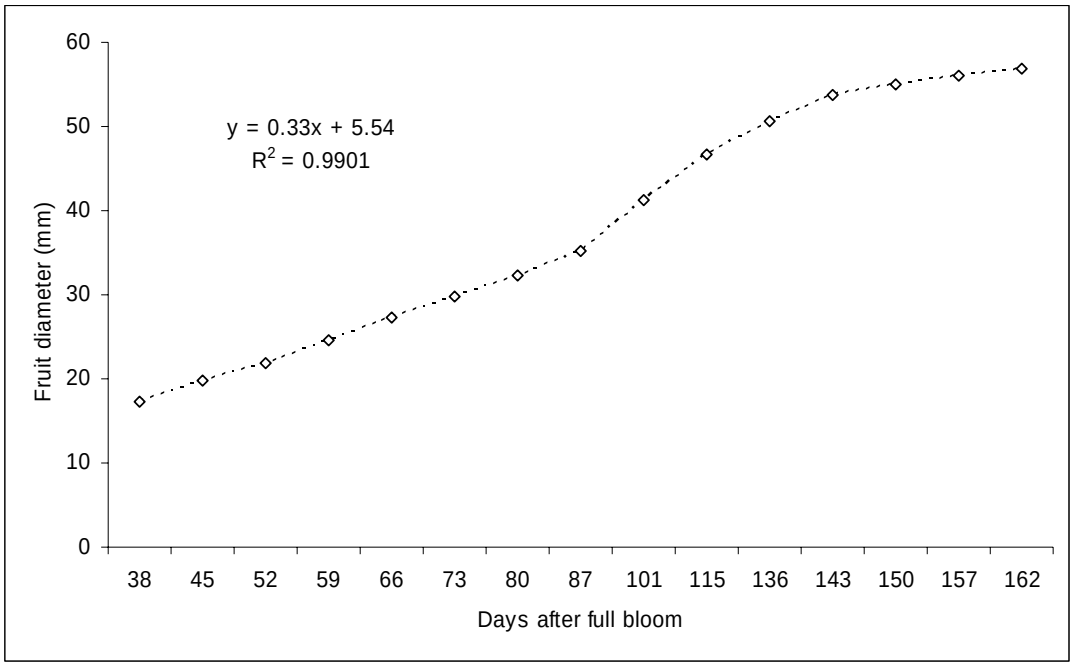

Fig. 10. Seasonal changes in 'Forelle' fruit diameter during the 2007/8 growing season.

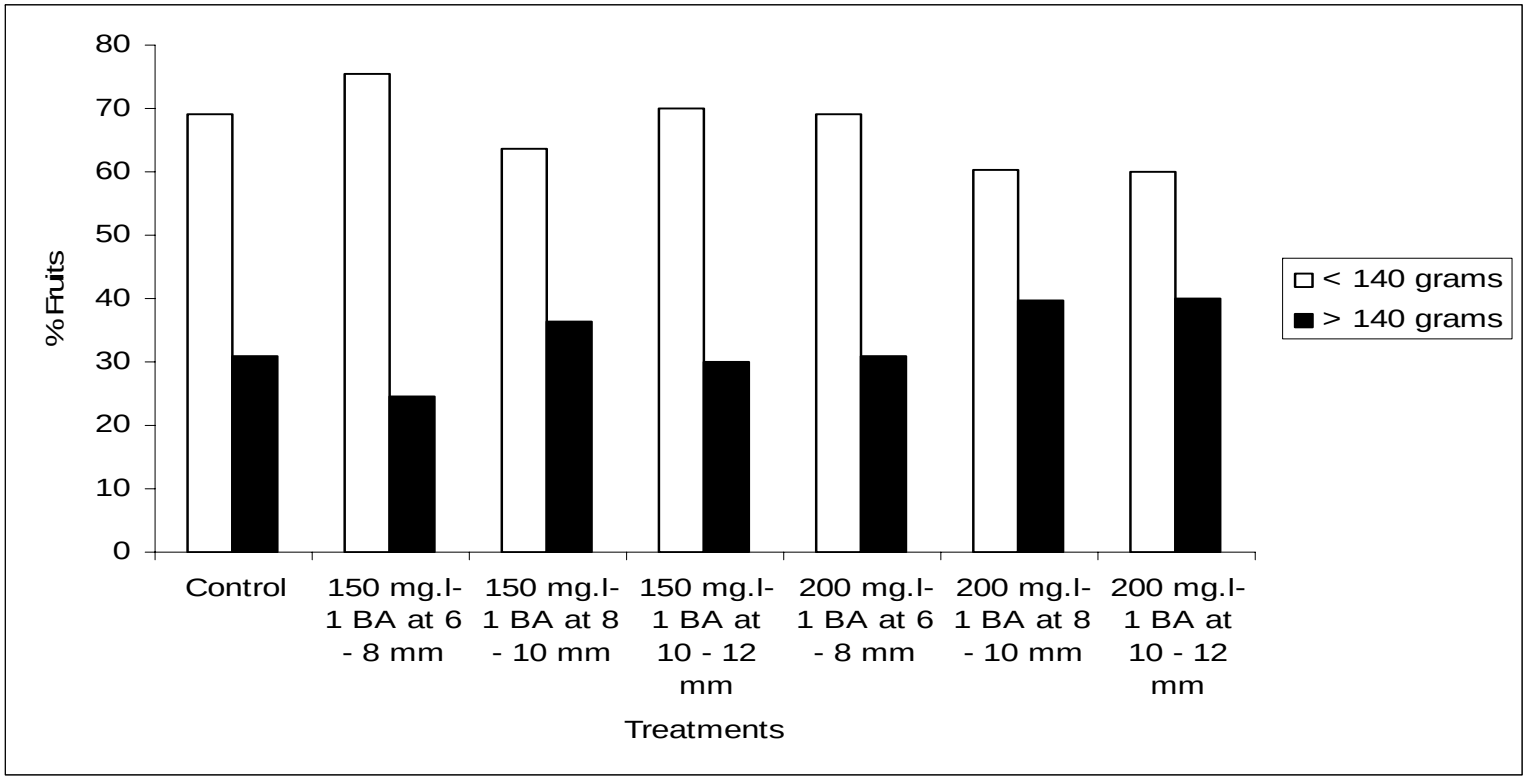

Fig. 11. Effect of different BA rates and application periods on fruit size distribution in 'Forelle' fruits at Buchuland, Ceres 2007/8 season.

CHAPTER 4

Possible mode of action and effect of timing of application of 6-benzyladenine as a post-bloom thinner on European pears (*Pyrus communis* L.)

Abstract

6-benzyladenine (BA) is a relatively new post-bloom thinning agent which reduces fruit set, thus promoting fruit growth and return bloom on pear trees. Three experiments were conducted to investigate the possible mode of action of BA and the effect of BA application time on two blushed pear cultivars, 'Forelle' and 'Rosemarie', in the Western Cape, South Africa, in the 2007/8 season. The effect of site of application on thinning efficacy of 200 $mg.l^{-1}$ BA on 'Forelle' was evaluated in the first experiment. BA did not significantly affect fruit abscission and fruit characteristics of 'Forelle' when applied directly to only fruit, only leaves or the whole clusters. In the second experiment, the effect of BA rates of 150 and 200 $mg.l^{-1}$ on bourse shoot growth and fruit abscission was evaluated. BA did not significantly affect bourse shoot growth and fruit abscission on 'Forelle' and 'Rosemarie'. The effect of timing and fruit size at application time on the efficacy of BA at 200 $mg.l^{-1}$ on 'Forelle' was evaluated in the third experiment. In terms of fruit abscission, there was a statistically significant interaction between application time and fruitlet size. Early (8 d.a.f.b.) applications were more effective than later (11 and 17 d.a.f.b.) applications. Abscission was highest on fruits in the 6 to 8 mm category whilst the 8 to 10 mm category was unresponsive to BA at all stages of application. The 11 d.a.f.b. application was ineffective whilst the 17 d.a.f.b. application resulted in a linear response, with abscission of larger fruit (10 to 12 mm) inhibited relative to the untreated control. We concluded that, early BA applications promote abscission of smaller fruitlets while late(r) BA applications inhibit abscission of larger fruit.

Keywords: abscission; benzyladenine; bourse shoot; fruit diameter; fruit size; fruit weight.

Introduction

Chemical thinning to reduce fruit set, improve fruit size and quality, and return bloom has become a standard management practice in some commercial pear orchards. Based on results from fairly recent trials, the post-bloom thinning agent 6-benzyladenine (BA) has yielded the most promising results on European pear cultivars (Wertheim, 2000; Webster, 2002a). BA has a unique advantage over other thinning agents, in that, as a synthetic cytokinin, it can increase fruit size without a notable reduction in crop load (Bubán, 2000; Webster, 2002a).

However, little is known about the mode of action of BA when used as a chemical thinning agent (Bubán, 2000; Wertheim, 2000). According to Bangerth (2000), BA preferably acts via leaves. Greene *et al.* (1992) found BA more effective in promoting apple fruit abscission when applied directly to only the leaves than to only the fruit. Fruit size was increased only when BA was applied directly to the fruit, this occurred without significantly reducing fruit set (Greene *et al.,* 1992). BA promotes fruit growth by prolonging the phase of mitotic cell division in developing fruits (Shargal *et al.,* 2006). The final fruit size of pears at harvest is determined by both cell division and cell expansion within the fruits (Westwood, 1993; Jackson, 2003).

Yuan and Greene (2000) suggested that BA induces fruitlet abscission by inhibiting photosynthesis and stimulating dark respiration in apple, thereby reducing the supply of assimilates to the developing fruits. However, according to Stopar *et al.* (1997), BA does not appear to affect leaf assimilation. Therefore, the mode of action of BA may involve a transient stimulation of the growth of lateral side shoots, such as the bourse shoot (Williams, 1994; Jackson, 2003). Where shoots adjacent to fruit are growing vigorously, their high levels of IAA export results in correlative inhibition of IAA export from young fruits, leading to the abscission of some of them (Bangerth, 2000). The movement of natural hormones is believed to play a role in determining sink strength and movement of assimilates, however, there is little objective evidence to support this hypothesis (Webster, 2002b).

The recommended application period for BA as a post-bloom thinning agent is when fruitlets are 7 to 12 mm (most often 10 - 12 mm) diameter, which is 14 to 21 d.a.f.b. (Bubán, 2000; Bertelsen, 2002). However, this range is based on average fruit diameter, and at times, the king fruit diameter (Stover *et al.,* 2001), on the lower branches of the tree. Fruit size, even at only a few d.a.f.b. is normally distributed within the tree canopy. In South Africa, the lack of winter chilling further influences the range of fruit sizes and distribution in the tree. Therefore, the size of the fruitlets on the spray date may vary considerably. This variation in fruitlet size may be, in part, the cause of the variable results obtained when using BA to thin European pear cultivars such as ‘Conference’ (Wertheim, 2000; Vilardell *et al.,* 2005), as the degree of fruit thinning is influenced by the fruit diameter at the time of application (Marini, 1998).

The purpose of this study was to evaluate (i) the effect of site of BA application on fruit thinning and fruit size at harvest and (ii) the effect of BA on bourse shoot growth and fruit drop, and (iii) the effect of fruit size at application time on thinning efficacy of BA.

Materials and Methods

Experiment 1

Plant material

The trial was conducted during the 2007/8 season at Buchuland Farm, which is situated in the Ceres (33°15′ S, 19°15′ E) area of the Western Cape, South Africa. The area is situated in a Mediterranean climatic region which is characterised by warm, dry summers and cool, wet winters. The 'Forelle' trees on BP3 rootstock were planted in 1995 with 'Kieffer' as the cross pollinator. The trees were trained to a central leader, displayed uniform bloom density and good vegetative growth. Commercial ProGibb® (GA_3) was applied at 30 % bloom for fruit set, as per standard farm practice. Harvesting of experimental fruit was undertaken on the same day as the commercial harvest.

Treatments and experimental design

MaxCel ™, containing 1.9 % (w/w) of 6-BA was applied at 10 to 12 mm fruit size (17 d.a.f.b.) using a hand-held spray gun. Surfactants were not added to the spray solution. 200 $mg.l^{-1}$ BA was applied directly to (1) fruitlets only, (2) leaves only and (3) fruitlets and leaves (whole clusters), with at least four fruits per cluster and compared to an untreated control. Plastic sheets were used to cover the parts of the cluster that were not sprayed. A randomised complete block design with 10 (four-cluster plot) replications of four treatments was used for the trial.

Data collected

Fruit set per cluster on the four tagged clusters/tree was recorded 36 d.a.f.b. At harvest (10 March 2008, 170 d.a.f.b.), all the remaining fruit were collected and analysed for the following fruit quality parameters; fruit diameter, length, weight, firmness and seed content. Fruit firmness was measured with a GÜSS fruit texture analyser (Model GS-14, Guss Manufacturing Ltd., Strand, South Africa, with a plunger diameter of 8 mm) directly into the flesh on paired, opposite sides of each fruit.

Experiment 2

Plant material

The trial was conducted during the 2007/8 season at Welgevallen Experimental Farm (34°55' S; 19°02'E), situated in the Stellenbosch area of the Western Cape, South Africa. 'Forelle' and 'Rosemarie' trees with even vegetative growth were used. The 'Forelle' trees on quince rootstock were planted in 1998 with a 'Beurre Hardy' interstock at a spacing of 3.8 m x 1.25 m in a North-South row orientation. 'Kieffer' is the cross pollinator at a density of 10 %. The 'Rosemarie' trees were planted on BP1 rootstock in 1992 at a spacing of 4.5 m x 2.0 m with the same row orientation as the 'Forelle'. 'Early Bon Chrétien' and 'Packham's Triumph' were the cross pollinators at a density of 6.6 % and 3.3 %, respectively. Both of these cultivars are trained to a 3-wire-trellis central leader system. Commercial ProGibb® (GA_3) was applied at 30 % bloom for fruit set as per standard farm practice.

Treatments and experimental design

MaxCel ™, containing 1.9 % (w/w) of 6-BA was applied at 14 to 16 mm fruit size using a hand-held spray gun. Surfactants were not added to the spray solution. Two rates of BA, 150 and 200 $mg.l^{-1}$were applied to randomly selected fruit clusters (with at least two fruits per cluster) and a bourse shoot and compared to an untreated control. A complete randomised design with 10 single-cluster plots per replication of three treatments was used for the trial.

Data collected

The length of the bourse shoot was measured and fruit number per plot (cluster) was recorded on the spray date (29 November 2007) and on three day intervals for 28 days after BA application.

Experiment 3

Plant Material

The same site as in Experiment 1 was used.

Treatments and experimental design

MaxCel ™, containing 1.9 % (w/w) of 6-BA was applied at a rate of 200 $mg.l^{-1}$, to whole trees, 8, 11 and 17 d.a.f.b. and compared to an unsprayed control. Ten fruitlets of each fruit

size category, 6 to 8, 8 to 10, 10 to 12 mm fruit diameter where tagged per tree on the respective application dates (See Table 1). All chemicals were applied with a motorised knapsack sprayer. Surfactants were not added to the spray solution. A randomised complete block design with 10 single-tree plot replications of four treatments was used for the trial.

Data collected

The number of fruits that persisted on the tree 30 days after full bloom was counted and the number of fruits that abscised was determined.

Statistical analysis

The General Linear Models (GLM) procedure of the Statistical Analysis System (SAS® 9.1.2, SAS Institute Inc, 2004, Cary, NC) was used to analyse the data.

Results

Experiment 1

There were neither significant differences nor apparent trends among application site treatments in terms of fruit abscission, fruit diameter, weight and firmness (Table 2; 3). However, the fruit application treatment resulted in the highest increase in fruit weight of ± 6 % of the control (Table 3). The leaf and the fruit + leaf application resulted in a significant increase in fruit length relative to the control (Table 3). There were no significant differences or apparent trends among treatments in terms of fruit malformation and seed abortion (Table 3; 4).

Experiment 2

There were no significant differences among treatments in terms of bourse shoot development on 'Forelle' pear (Table 5). The control shoots did not grow at all (Table 5; Fig. 1). None of the control shoots were actively growing at application time, while with 200 and 150 $mg.l^{-1}$ treatments, 10 and 20 % of bourse shoots were actively growing, respectively (Table 5). In this trial, bourse shoot growth generally ceased 12 days after BA application (Fig. 1). There were no significant differences or apparent trends among treatments on fruit abscission (Table

5).

No significant differences were found between treatments on bourse shoot growth of 'Rosemarie' pear trees (Table 6). The highest BA rate, 200 $mg.l^{-1}$ resulted in the greatest increase in bourse shoot length, while the smallest increase was observed on the control (Table 6; Fig. 2). Only 20 % of control shoots and 30 % of the BA- treated were actively growing at time of BA application (Table 6). Bourse shoot growth ceased approximately 14 days after BA application (Fig. 2). There were neither significant differences nor apparent trends among treatments in terms of fruit abscission (Table 6).

Experiment 3

There was a statistically significant interaction (P = 0.0467) between time of BA application and fruitlet size on fruit abscission. From Table 7 it is clear that the interaction stems from the different responses of the size categories to BA at the different stages of application. The size category 6 to 8 mm became linearly (P = 0.0007) less susceptible to BA with later application, while the category 8 to 10 mm was relatively unresponsive to BA at all stages of application. In the case of the 10 to 12 mm category, there was again a very strong linear response (P = 0.0002) to BA application time, with later applications less successful in reducing set (Table 7).

On the other hand, when time of application is evaluated the quadratic trend (P = 0.0120) observed at 8 d.a.f.b. indicates that smaller (6 to 8 mm) and larger (10 to 12 mm) fruit are more susceptible to BA application than the middle category of 8 to 10 mm (Table 7). The application stage 11 d.a.f.b. was ineffective, while the 17 d.a.f.b. application of BA resulted in a linear response (P = 0.0187) indicating a lessening in susceptibility the bigger the fruit were (Table 7).

Differences in abscission between the three tagged fruit size categories of the control treatment were statistically significant (P = 0.0009). Percentage fruit abscission in the 6 to 8 mm fruit size category was significantly higher than that of the other two categories (8 to 10 and 10 to 12 mm) resulting in a quadratic response (P = 0.0020) (Table 7).

Discussion

Experiment 1

BA applied to the leaves alone, or both to the leaves and fruit results in comparable thinning in apple (Greene 1989; 1993). However, in our trials when applied to whole clusters, fruit only or leaves only, BA did not promote fruit abscission and no apparent trend was observed among treatments (Table 2). An application of 200 $mg.l^{-1}$ BA at 10 to 12 mm fruit size should have been ideal and sufficient to induce fruit abscission (Bubán, 2000; Wertheim, 2000; Bertelsen, 2002). However, since 'Forelle' is a small fruited variety (Huysamer, 1997), the ideal application time might be earlier than for a bigger fruited cultivars if they need to be at a specific phenological stage in terms of vascular and seed development (Theron, pers comm.). In addition the rate of BA might have been too low. The same observations were reported on the same cultivar in Chapter 3, where 200 $mg.l^{-1}$ BA applications at an average fruit size of 10 to 12 mm did not significantly reduce average fruit set per cluster on two tagged branches.

According to Greene (1993), the direct application of BA to the fruit is important to influence fruit size and flesh firmness. This is because, cytokinin applications to a single site in the plant causes the treated organ to become an active sink for assimilates and amino acids, which then migrate to the organ from surrounding sites (George *et al., 2008*). However, fruit diameter, weight and firmness were not significantly enhanced by 200 $mg.l^{-1}$ BA applications at any site (Table 3). In Chapter 3 we reported that 200 $mg.l^{-1}$ BA applied at an average fruit size of 10 to 12 mm did not significantly increase fruit diameter, however, fruit weight was significantly improved. The inability of 200 $mg.l^{-1}$ BA to improve fruit diameter and weight can be attributed to its failure to reduce fruit set (Table 2). While BA is capable of increasing fruit size without any apparent reduction in crop load (Bubán, 2000; Webster, 2002a; Stern and Flaishman, 2003), a reduction in crop load is often a prerequisite to fruit size improvement in some cultivars and some seasons (Webster, 2002b). BA at 200 $mg.l^{-1}$ at any site of application, did not have an effect on malformation and seed abortion (Table 4). This is in agreement with results reported by Dussi *et al*. (2008) on 'Williams Bon Chrétien', where 200 $mg.l^{-1}$ BA had no effect on fruit shape and seed number. The same observations were reported on 'Forelle' in Chapter 3, where 200 $mg.l^{-1}$ BA at an average fruit size of 10 to

12 mm did not affect fruit shape and seed number.

Experiment 2

Benzyladenine is known to stimulate the growth of vegetative side shoots, such as bourse shoots (Jackson, 2003; Bubán, 2000). A high level of IAA export out of these young vegetative shoots correlatively inhibits IAA export from young fruits, resulting in fruit abscission (Bangerth, 2000). However, in our trials, bourse shoot growth and fruit abscission were not stimulated significantly (Table 5; 6). The recommended application time for BA is 10 to 12 mm fruit size (Bubán, 2000; Bertelsen, 2002). In our experiment, we applied BA at 14 to 16 mm fruit size and this is probably too late to induce fruit abscission on 'Forelle' and 'Rosemarie'. It must also be noted that in the 2007/8 season, blossom density was relatively low which reduces responsiveness to chemical thinning agents (Williams, 1994) and this could have been further aggravated by considerable damage done to the trees by dormancy-breaking agents in this orchard.

The lack of shoot growth promotion stimulated by BA can possibly be attributed to the fact that the applications were made relatively late and only very few bourse shoots were actually actively extending (Table 5, 6). Apparently the BA rate applied was too low to stimulate a new growth flush. The differences between bourse shoot development between these two cultivars can also be attributed to the tendency for 'Rosemarie' to form a strongly growing bourse shoot, whereas 'Forelle' does not often form bourse shoots longer than 1 to 2 cm (Du Plooy *et al.,* 2002; Reynolds e*t al.,* 2004).

Since not all fruit cultivars produce bourse shoots, the 'bourse shoot hypothesis' is not always applicable. According to Yuan and Greene (2000), BA induces fruitlet abscission by inhibiting photosynthesis and stimulating dark respiration, thereby reducing the supply of carbohydrates to apple fruit. Net photosynthesis was inhibited by 10 to 15 % in apple whilst leaf carbohydrate levels were reduced by 50 or 100 $mg.l^{-1}$ BA applications (Yuan and Greene, 2000). BA is also believed to induce ethylene evolution (Greene 1989; Bubán, 2000), which inhibits the synthesis and translocation of IAA by fruits, reducing sink strength leading to the abscission of the smaller and weaker lateral fruits (Bangerth, 2000). The stimulation of abscission by BA is possibly a combination of these three mechanisms to varying degrees.

Experiment 3

Results obtained from this experiment indicate that, both the time of application and fruitlet size influence the efficacy of BA. The highest amount of abscission was observed on fruits in the 6 to 8 mm category. This is probably because small fruitlets are more susceptible to fruit drop as they would not yet have developed seeds and well differentiated vascular tissues which have an influence on sink strength. The embryo and/or endosperm are the primary source(s) of endogenous hormones in seeded fruit (Martin *et al.,* 1977; Ozga and Reinecke, 2003). The endosperm of 'Conference' and 'Doyenné du Comice' seeded fruits, becomes cellular whilst the embryo starts to grow rapidly consisting of dozens of cells, reaching globular stage 35 - 40 days after pollination (Sniezko and Visser, 1987). This coincides with the main period of IAA efflux from fruits. Gil *et al*. (1973) observed an increase in IAA movement from 'Bon Chrétien' fruits from full bloom to 26 d.a.f.b., peaking 70 d.a.f.b. and declining sharply afterwards. IAA stimulates the differentiation of vascular tissues (Dengler, 2001), thus fruits with the lowest rates of IAA diffusion will fail to develop vascular connections and will ultimately abscise (Bangerth, 2004). Larger fruit (8 to 10 and 10 to 12 mm) were generally more persistent than smaller fruit (6 to 8 mm), confirming that, larger fruits have greater sink strength and are able to correlatively inhibit IAA export from small lateral fruits (Bangerth, 2000; 2004). Fruit in the middle (8 to 10 mm) category were more persistent than fruit in the 10 to 12 mm category. This was not expected as sink strength is believed to be positively correlated with fruit size (Bangerth, 2004).

Earlier (8 d.a.f.b.) BA applications were generally more effective than later (11 and 17 d.a.f.b.) applications (Table 7). This is probably because earlier applications are made when the fruitlets are at the earliest stages of fruit development and highest levels of competition amongst the developing fruits (Williams, 1994; Bound and Mitchell, 2002; Webster, 2002a). The quadratic trends observed on the most effective application time (8 d.a.f.b.) and on the untreated control (Table 7), suggest that BA reduces crop loads by magnifying natural fruitlet drop expressed at the moment of application (Bangerth, 2000; Wertheim, 2000).

Applications at 11 and 17 d.a.f.b. are less effective because this is probably the stage of fruit growth when the fruits have developed strong vascular connections and hormonal signals. It is also important to note that, late applications are possibly less effective in inducing fruit

abscission because a considerable amount of natural fruit drop will have occurred before applying the chemical. Therefore, the thinning compound is applied at a time when there is relatively less inter-fruit competition for assimilates. The 11 d.a.f.b. application was ineffective (Table 7). This is probably because it was applied at a less favourable temperature of 13 °C (Table 1). According to Bound *et al.* (1997), BA is only effective as fruit thinning agent at temperatures of ± 18 °C.

The 17 d.a.f.b. application resulted in a linear response for fruit abscission in relation to fruitlet size, with larger fruits being less susceptible. Late BA applications possibly inhibit abscission of large fruits, thus BA may actually increase sink strength of larger fruits when applied later. According to Bubán (2000), BA promotes an efflux of assimilates from the leaves adjacent to the application sites. Therefore, BA has an advantage over other post-bloom thinning agents in that it increases sink strength of bigger fruits. Late applications of other post bloom thinning agents such as NAA and NAD may actually inhibit fruit growth (Dennis, 2000; Wertheim, 2000: Webster, 2002a).

According to Bubán and Lakatos (2000), BA is effective when there is an increase and ineffective when there is a decrease in mean daily temperatures 5 to 10 days after application. Results obtained from this experiment suggest that, the interactive effect between fruit size and time of BA application on fruit abscission is probably more stronger than the effect of temperature (after application) on BA efficacy. This is because, although the 8 d.a.f.b. application was the most effective treatment (Table 7), a sharp decrease in mean daily temperatures 5 days after the BA application at this timing (Fig. 3). On the other hand, the 17 d.a.f.b. treatment was less effective (Table 7) despite the sharp increase in mean daily temperatures 5 days after BA application at this timing (Fig. 3). The 11 d.a.f.b. application was ineffective (Table 7), this is probably because there were no appreciable differences in mean daily temperatures 5 days (fluctuating between 7.4 and 11.6 °C) after the 11 d.a.f.b. application (Fig. 3).

Conclusion

The results obtained from these experiments were generally inconclusive. In the first experiment, site of application of BA had no effect on fruit set and fruit size, however

applying BA directly to the fruit slightly increased fruit diameter and weight. BA did not have a negative effect on fruit quality and seed number. In the second experiment, BA induced bourse shoot growth only slightly, however this was not statistically significant and no accompanying fruit abscission was observed. Ten replications were used in Experiment 1 and 2, these could have been too few to evaluate such highly variable responses (fruit abscission and bourse shoot growth). The low blossom density and initial fruit set observed on the trees in Experiment 2, could have contributed to the lack of response. In the third trial, the effect of application time and fruitlet size on fruit abscission was an interactive one. BA applications at 8 d.a.f.b. (i.e. at 6 to 8 mm average fruit size) were more effective in promoting fruit abscission than at 11 and 17 d.a.f.b. Therefore, the recommended average fruit size/ spray period for application of thinning agents, 7 to 12 mm diameter (Bubán, 2000; Bertelsen, 2002) is accurate for European pear cultivars. The lower average fruit size, 7 mm, will probably be the ideal stage to apply thinning agents on difficult–to-thin cultivars such as 'Forelle', while the widely used range, 10 to 12 mm fruit size might be the ideal stage to apply thinning agents on easy-to-thin cultivars such as 'Packham's Triumph.' This is because large fruited cultivars have a faster fruit growth rate relative to phenological development (Theron, pers comm). BA applications increase sink strength of larger fruit and therefore later applications particularly resulted in less abscission of larger fruits relative to the untreated control. Therefore BA has an advantage over other post bloom thinning agents in that it stimulates fruit drop of small fruit and inhibits fruit drop/ increases sink strength of bigger fruits.

References

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

Bangerth, F. 2004. Internal regulation of fruit growth and abscission. *Acta Hort.* 636: 235 - 248.

Bertelsen, M.G. 2002. Benzyladenine and other thinning agents for pear cv. 'Clara Frijs'. *J. Am. Pomol. Soc.* 56: 149 - 155.

Bound, S.A. and Mitchell, L. 2002. A new post-bloom thinning agent for 'Packham's Triumph' pear. *Acta Hort.* 596: 793 - 796.

Bound, S.A., Jones, K.M. and Oakford, M.J. 1997. Post-bloom thinning with 6-benzyladenine. *Acta Hort.* 463: 493 - 499.

Bubán, T. 2000. The use of benzyladenine in orchard fruit growing: a mini review. *Plant Growth Regul.* 32: 381 - 390.

Dengler, N. 2001. Regulation of vascular development. *J. Plant Growth Regul.* 20: 1 - 13.

Dennis, F.G. 2000. The history of fruit thinning. *Plant Growth Regul.* 31: 1 - 16.

Du Plooy, P., Sadie, A., Jacobs, G., Cook, N.C., 2002. Branching habit of two-year-old pear branches classified on the basis of length and position of one-year-old laterals. *Scientia Hort.* 95: 193 - 201.

Dussi, M.C., Giardina G., Reeb, P. and Gastiazoro, J. 2008. Thinning programs in pears cv. Williams. *Acta Hort* (*accepted for publication*).

George, E.F., Hall, M.A. and De Klerk, G. 2008. Plant growth regulators II: cytokinins, their analogues and antagonists. pp. 205 - 226. In: George, E.F., Hall, M.A. and De Klerk, G. (Eds.), Plant propagation by tissue culture (3rd Ed.). Springer. Netherlands.

Gil, G.F., Martin, G.C. and Griggs, W.H. 1973. Fruit set and development in the pear: diffusible growth substances from seeded and seedless fruits. *J. Am. Soc. Hort. Sci.* 98: 51 - 54.

Greene, D.W. 1989. Regulation of fruit set in tree fruits with plant growth regulators. *Acta Hort.* 239: 323 - 334.

Greene, D.W. 1993. A review of the use of benzyladenine (BA) as a chemical thinner for apples. *Acta Hort.* 329: 231 - 236.

Greene, D. W., Autio, W. R., Erf, J. A., and Mao, Z. Y. 1992. Mode of action of benzyladenine when used as a chemical thinner on apples. *J. Am. Soc. Hort. Sci.* 117: 775 - 779.

Huysamer, M. 1997. The challenge of bi-coloured pear production. *Proc. Cape. Pom. Ass. Tech. Symp.* Cape Town. 168 - 173.

Jackson, J.E. 2003. Biology of apples and pears. Cambridge University Press.

Marini, R. 1998. Experience with thinning: What factors contribute to contradicting results? (Abstact). *HortScience* 33: 553.

Martin, G.C., Dennis F.G., MacMillan, J .and Gaskin, P. 1977. Hormones in pear seeds: 1. Levels of gibberellins, abscisic acid, phaeseic acid, dihyrophaseic acid, and two metabolites of dihydrophaseic acid in immature seeds of *Pyrus communis* L. *J. Am. Soc. Hort. Sci.* 102: 16 - 19.

Ozga, J.A. and Reinecke, D.M. 2003. Hormonal interactions in fruit development. *J. Plant Growth Regul.* 22: 73 - 81.

Reynolds, L.P., Jacobs, G. and Theron, K.I. 2004. Reproductive bud development of pears (*Pyrus communis* L.) with emphasis on the bourse shoot. *Acta Hort.* 671:165 - 170.

Shargal, A., Golobovich, S., Flaishman, M.A., Shlizerman, L.A., Stern, R.A., Grafi, G., Lev-Yadun, S. and Yablovich, Z. 2006. Synthetic cytokinins extend the phase of division of parenchyma cells in developing pear (*Pyrus communis* L.) fruits. *J. Hort. Sci. Biotechnol.* 81: 915 - 920.

Sniezko, R and Visser, T. 1987. Embryo development and fruit-set in pear induced by untreated and irradiated pollen. *Euphytica* 36: 287 - 294.

Stern, R.A and Flaishman, M.A. 2003. Benzyladenine effects on fruit size, fruit thinning and return yield of 'Spadona' and 'Coscia' pear. *Scientia Hort.* 98: 499 - 504.

Stopar, M., Black, B.L. and Bukovac, M.J. 1997. The effect of NAA and BA on carbon dioxide assimilation by shoot leaves of spur-type 'Delicious' and 'Empire' apple trees. *J. Am. Soc. Hort. Sci.* 122: 837 - 840.

Stover, E., Fargione, M., Risio, R., Yang, X. and Robinson, T. 2001. Fruit weight, crop load, and return bloom of 'Empire' apple following thinning with 6-Benzyladenine and NAA at several phenological stages. *HortScience* 36: 1077 - 1081.

Vilardell, P., Carbó, J., Casals, M., Bonany, J., Asín, L. and Dalmau, R. 2005. Effect of 6-BA and NAA as thinning agents of 'Conference' pear. *Acta Hort.* 671: 119 - 124.

Webster, A.D. 2002a. Current approved thinning strategies for apples and pears and recent thinning research in Europe. *Compact Fruit Tree* 35: 73 - 76.

Webster, A.D. 2002b. Factors influencing the flowering, fruit set and fruit growth of European pears. *Acta Hort.* 596: 699 - 709.

Wertheim, S.J. 2000. Developments in the chemical thinning of apple and pear. *Plant Growth Regul.* 31: 85 - 100.

Westwood, M.N. 1993. Temperate-zone pomology: physiology and culture (3rd Ed.), Timber Press. Portland, Oregon.

Williams, M.W. 1994. Factors influencing chemical thinning and update on new chemical thinning agents. *Compact Fruit Tree* 27: 115 - 122.

Yuan, R. and Greene, D.W. 2000. Benzyladenine as chemical thinner for 'McIntosh' apples. I. Fruit thinning effects and associated relationships with photosynthesis, assimilate translocation, and non-structural carbohydrates. *J. Amer. Soc. Hort. Sci.* 125:169 - 176.

Tables

Table 1. Timing of 200 mg.l^{-1} 6-benzyladenine (BA) applications on 'Forelle' trees on Buchuland farm, Ceres (Experiment 3).

Treatments			Size of Tagged fruit (10/ category)	Weather conditions on spray date
Number	Average fruit diameter on application date	Days after full bloom		
1	Unsprayed	Unsprayed	6 – 8 mm 8 – 10 mm 10 – 12 mm	
2	6 – 8 mm	8	6 – 8 mm 8 – 10 mm 10 – 12 mm	Temperature: 18.0 °C Relative Humidity: 59 %
3	8 – 10 mm	11	6 – 8 mm 8 – 10 mm 10 – 12 mm	Temperature: 13.0 °C Relative Humidity: 75 %
4	10 – 12 mm	17	6 – 8 mm 8 – 10 mm 10 – 12 mm	Temperature: 16.5 °C Relative Humidity: 54 %

Table 2. Effect of site of application of 200 $mg.l^{-1}$ 6-benzyladenine (BA) on fruit abscission of 'Forelle' pear

Site of application	Average number of fruit per cluster before BA application	Average number of fruit per cluster 36 d.a.f.b.	Average number of fruit per cluster at harvest
Control	6.30 ns	3.33 ns	1.25 ns
Fruit only	6.00 ns	3.50 ns	1.65 ns
Leaves only	6.40 ns	3.15 ns	1.65 ns
Fruits and Leaves	6.30 ns	3.65 ns	1.28 ns
Significance level	*0.5379*	*0.2679*	*0.2496*
LSD	0.64	0.53	0.54

Treatment means followed by the same letter are not significantly different at 5 % level (LSD)

Table 3. Effect of site of application of 200 mg.l^{-1} 6-benzyladenine (BA) on fruit size and firmness of 'Forelle' pear at harvest.

Site of application	Average fruit diameter (mm)	Average fruit length (mm)	Average fruit weight (g)	Fruit firmness (kg)
Control	61.58 ns	75.39 b	129.96 ns	6.65 ns
Fruit only	62.37 ns	78.06 ab	137.61 ns	6.55 ns
Leaves only	61.92 ns	79.85 a	136.95 ns	6.60 ns
Fruits and Leaves	60.03 ns	80.01 a	130.32 ns	6.81 ns
Significance level	*0.0988*	*0.0167*	*0.3383*	*0.3399*
LSD	1.94	3.09	11.08	0.30

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 4. Effect of site of application of 200 mg.l^{-1} 6-benzyladenine (BA) on fruit malformation and seed abortion of 'Forelle' pear at harvest.

Site of application	% Malformed fruit	Number of well - developed seeds	Number of aborted seeds
Control	10.72 ns	0.03 ns	9.80 ns
Fruit only	3.83 ns	0.01 ns	9.87 ns
Leaves only	1.99 ns	0.01 ns	9.71 ns
Fruits and Leaves	4.53 ns	0.00 ns	9.47 ns
Significance level	*0.6745*	*0.4115*	*0.3716*
LSD	0.20	0.15	0.49

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 5. Effect of different 6-benzyladenine (BA) rates on bourse shoot growth and fruit abscission of 'Forelle' pear at Welgevallen, Stellenbosch, 2007/8 season.

Treatment	Average increase in bourse shoot length (cm)	Average number of abscised fruits	Percentage of bourse shoots actively growing at time of BA application
Control	0.00 ns	0.20 ns	0
150 $mg.l^{-1}$	4.63 ns	0.00 ns	20
200 $mg.l^{-1}$	1.15 ns	0.00 ns	10
Significance level	*0.2213*	*0.1248*	-
LSD	5.54	0.22	-
Contrasts			
Treatments Lin	*0.6734*	*0.0772*	-
Treatments Quad	*0.0942*	*0.2982*	-

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 6. Effect of different 6-benzyladenine (BA) rates on bourse shoot growth and fruit abscission of 'Rosemarie' pear at Welgevallen, Stellenbosch, 2007/8 season.

Treatment	Average increase in bourse shoot length (cm)	Average number of abscised fruits	Percentage of bourse shoots actively growing at time of BA application
Control	4.30 ns	0.50 ns	20
150 $mg.l^{-1}$	6.15 ns	0.10 ns	30
200 $mg.l^{-1}$	10.75 ns	0.30 ns	30
Significance level	*0.4964*	*0.2545*	-
LSD	11.36	0.48	-
Contrasts			
Treatments Lin	*0.2545*	*0.4036*	-
Treatments Quad	*0.7766*	*0.1532*	-

Treatment means followed by the same letter are not significantly different at 5 % level (LSD).

Table 7. Effect of three different application times (of 200 mg.l^{-1} BA) and fruit size categories on % fruit abscission of 'Forelle' pear trees at Buchuland farm, Ceres, 2007/8 season.

Treatment	Size of tagged fruit on application date			*Significance level*	*Treatment Lin.*	*Treatment Quad.*
	6 - 8 mm	8 - 10 mm	10 - 12 mm			
Control	58	26	38	*0.0009*	*0.0107*	*0.0020*
8 d.a.f.b. (6 to 8 mm average fruit size)	69	38	50	*0.0079*	*0.0377*	*0.0120*
11 d.a.f.b. (8 to 10 mm average fruit size)	41	38	43	*0.7200*	*0.7489*	*0.4625*
17 d.a.f.b. (10 to 12 mm average fruit size)	37	23	13	*0.0571*	*0.0187*	*0.8064*
Significance level	*0.0020*	*0.1117*	*0.0011*			
Treatment Lin.	*0.0007*	*0.0504*	*0.0002*			
Treatment Quad.	*0.1073*	*0.3100*	*0.1311*			

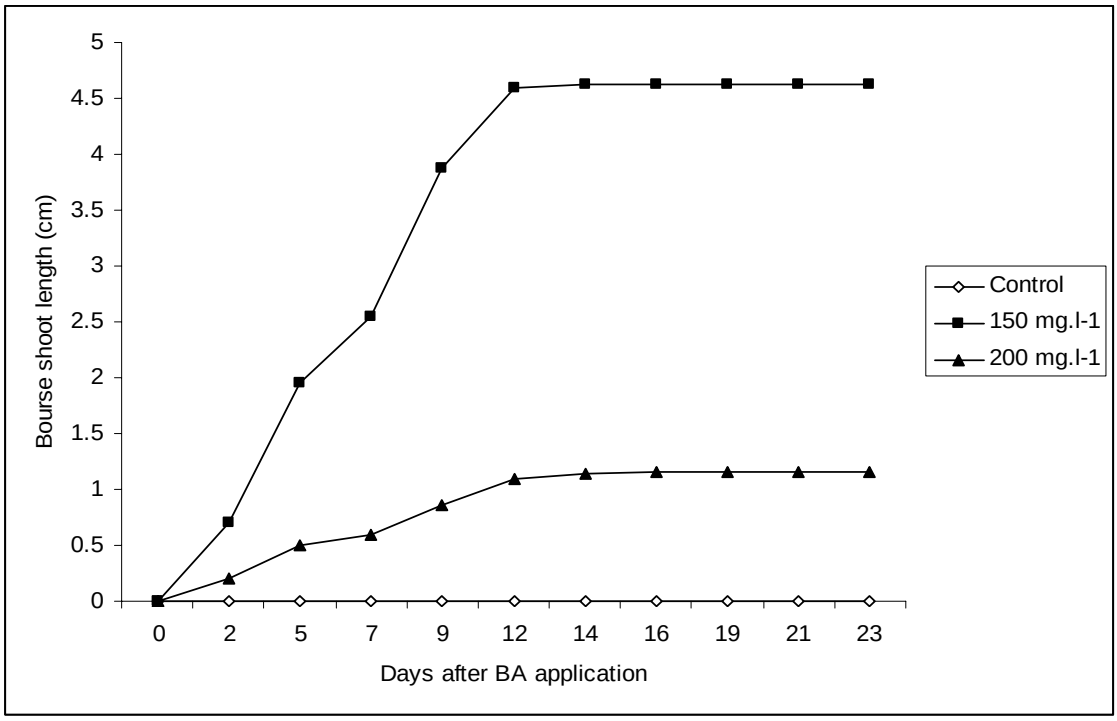

Fig. 1. Effect of two 6-benzyladenine (BA) rates on bourse shoot growth of 'Forelle' pear at Welgevallen in the 2007/8 season.

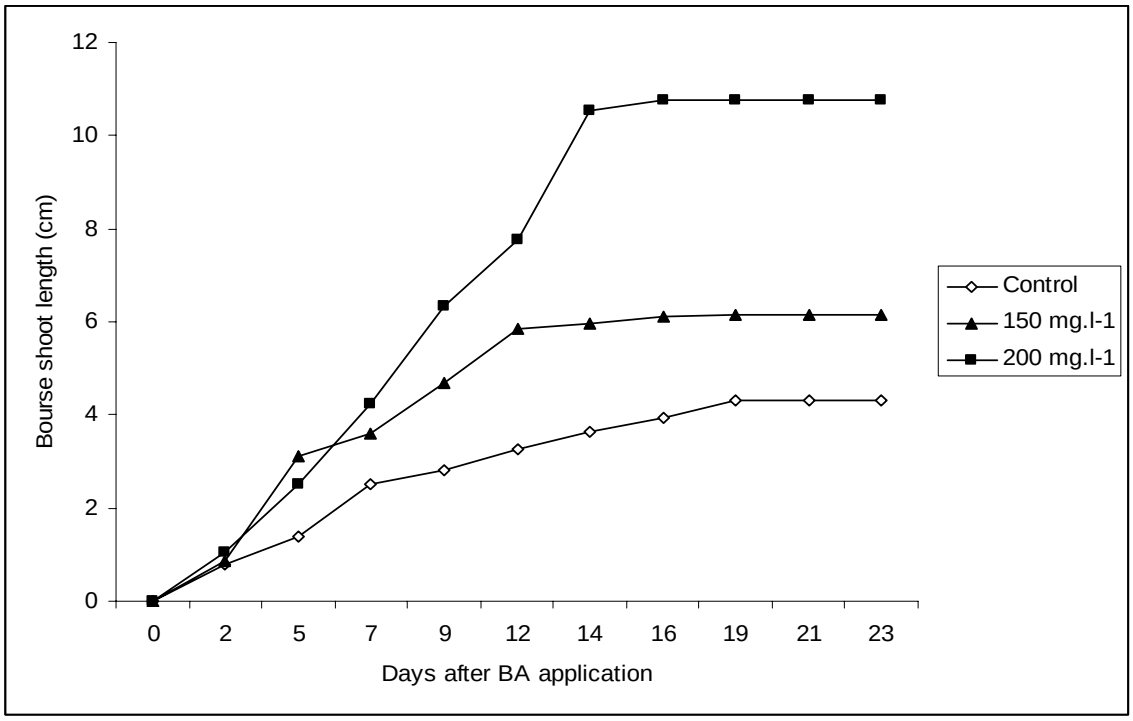

Fig. 2. Effect of two 6-benzyladenine (BA) rates on bourse shoot growth of ‘Rosemarie’ pear at Welgevallen in the 2007/8 season.

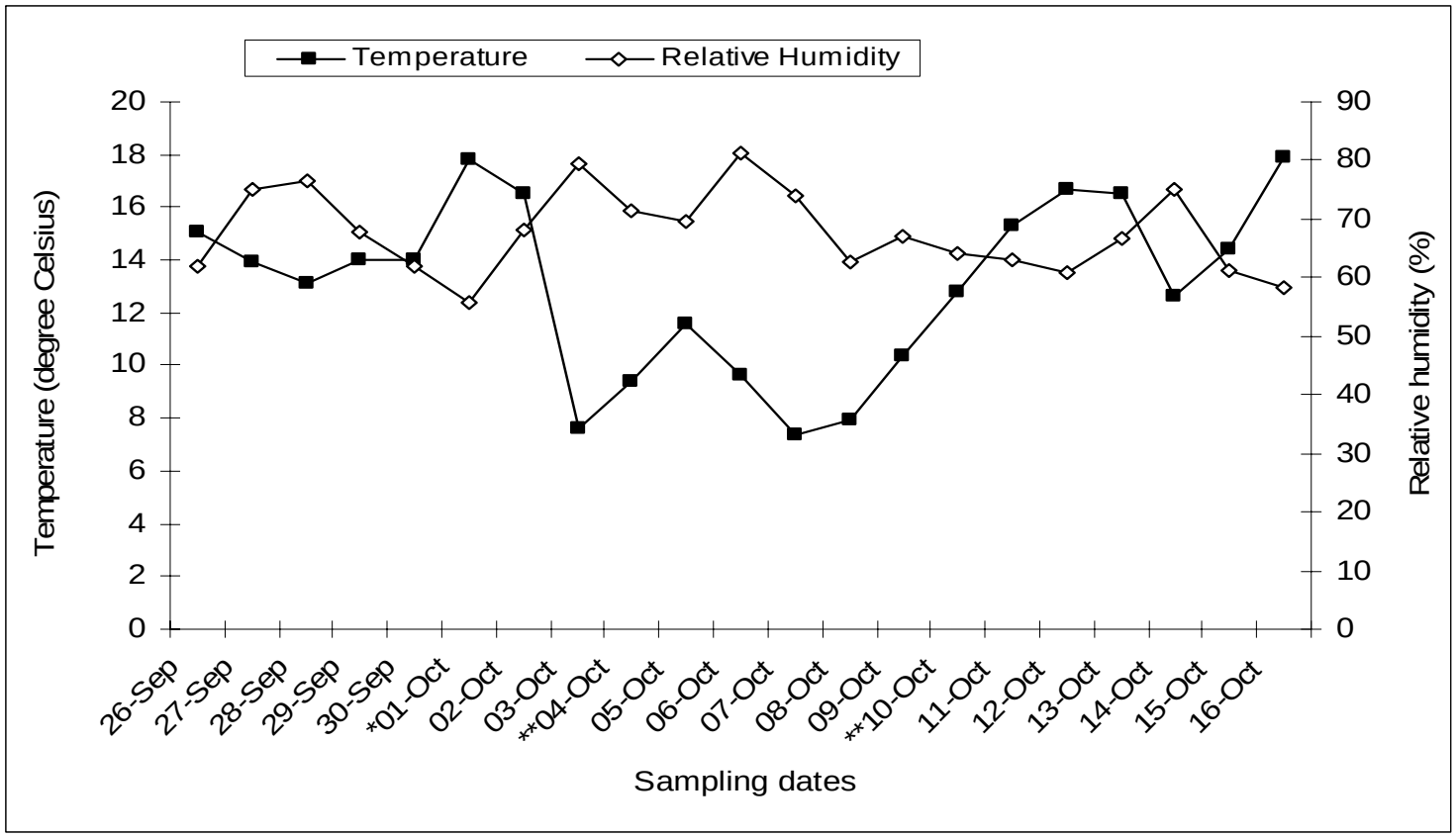

Fig. 3. Mean daily temperature and humidity from 26 September to 16 October 2007 at Buchuland farm, Ceres.

*First spray date (6 to 8 mm fruitlet size i.e. 8 d.a.f.b.)

**Second spray date (8 to 10 mm fruitlet size i.e. 11 d.a.f.b.)

***Third spray date (10 to 12 mm fruitlet size i.e. 17 d.a.f.b.)

GENERAL CONCLUSION

Temperate fruit trees growing under conditions favourable for flowering and fruit set often require some form of thinning prior to 60 days after full bloom (d.a.f.b.) to ensure that the remaining fruits reach sizes of commercial value. Thinning by hand requires much manual dexterity and therefore requires high labour input. The unavailability of labour as well as high labour costs have necessitated the evaluation of various chemical thinning agents to reduce crop load and labour costs whilst improving fruit size and return bloom.

In our trials, the synthetic cytokinin 6-benzyladenine (BA) produced promising results on 'Early Bon Chrétien', but less so on 'Forelle' pears. BA has a unique advantage over other commonly used post bloom thinning agents in that it can improve fruit size to a greater degree than can be expected from the effect of reducing crop load. Research papers cited in this study suggest that synthetic cytokinins such as BA can stimulate fruit growth independent of crop load by prolonging the phase of mitotic cell division in developing fruits. BA at100 or 150 $mg.l^{-1}$ induced a notable reduction in crop load and an increase in fruit size and return bloom of 'Early Bon Chrétien' pear, whilst higher rates of 150 to 200 $mg.l^{-1}$ BA were needed to improve fruit size of 'Forelle'. It has been suggested earlier that fruit sizes in characteristically small-fruited pear cultivars such as 'Conference' and 'Forelle' is a result of inadequate endogenous cytokinin levels to induce and prolong mitotic division of parenchyma cells in developing fruits. BA also improved return bloom in most of the trials. It is widely accepted that cytokinins promote flower bud formation directly by ensuring sufficient meristematic activity for differentiation and development of reproductive parts.

BA was more effective in reducing fruit set and improving fruit size, fruit size distribution and return bloom of 'Early Bon Chrétien' than on 'Forelle'. This was probably due to a number of genetic factors. 'Forelle' has poor bourse shoot growth as compared to 'Early Bon Chrétien'. Since the mode of action of BA possibly involves stimulation of vegetative growth, this could be the reason why the results on 'Early Bon Chrétien' were more favourable. 'Forelle' is relatively light flowering, thus more difficult to thin than the heavy flowering 'Early Bon Chrétien'. 'Forelle' also has a lower number of flowers per cluster than 'Early Bon Chrétien', therefore, less inter-sink competition within the cluster. 'Forelle' also

has fewer seeds per fruit than ‘Early Bon Chrétien’, therefore there is more or less uniformity in sink strength and thus a lower degree of primigenic dominance. The standard application of Progibb® (GA_3) at 30 % bloom to promote fruit set in ‘Forelle’, results in uniformity in sink strength.

Naphthylacetamide (NAD) is a registered post-bloom thinning agent of apples and pears in South Africa. NAD is a synthetic auxin which, along with naphthaleneacetic acid (NAA), were the first compounds found to reduce crop loads in fruit trees. However, they have variable effects, they often inhibit fruit growth and can be highly phototoxic in cool humid conditions. They can also promote fruit set when applied after a period of high humidity or rainfall. NAD was evaluated on ‘Early Bon Chrétien’ at rates of 30 and 40 $mg.l^{-1}$, but gave variable results in terms of fruit size. NAD at 30 $mg.l^{-1}$ slightly improved return bloom while reducing fruit set. However, the higher rate of NAD did not improve return bloom which is probably because auxins applied early have a synergistic inhibitory effect with seed and shoot produced gibberellins on flower bud induction.

Experiments conducted to investigate the mode of action of BA on European pear cultivars yielded inconclusive results. However, it is clear that early BA applications are more effective in inducing fruit abscission in ‘Forelle’. BA induces abscission of smaller fruits (< 8 mm diameter) but was less effective in stimulating abscission of larger fruits (> 10 mm diameter).

Concluding statement

In this study, it was shown that BA is a promising post-bloom thinning agent under South African conditions. Easy-to-thin cultivars such as ‘Early Bon Chrétien’ require lower rates of 100 to 150 $mg.l^{-1}$ at 8 to 12 mm fruit size and difficult-to-thin cultivars such as ‘Forelle’ require higher rates of 150 to 200 $mg.l^{-1}$ applied ± 11 d.a.f.b. or at 8 to 10 mm fruit size. Fruit size at application, in relation to phenological stage of fruit development time has an important effect on the efficacy of BA. Therefore research on the effect of phenological stage of fruit development and peak export of fruit/seed-produced phytohormones in relation to fruit manipulation may become of great importance in the future to improve the efficacy of post-bloom thinning agents on European pear cultivars. In addition, it might be interesting to evaluate the interaction of BA and other thinning agents for ‘Forelle’.