

Effect of rest-breaking and fruit thinning treatments on
reproductive development in apple

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DECLARATION

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SUMMARY

EFFECT OF REST BREAKING AND FRUIT THINNING TREATMENTS ON REPRODUCTIVE DEVELOPMENT IN APPLE

Lack of winter chilling is a major problem in producing temperate-zone fruit in warm climates. Delayed foliation and protracted bud burst and flowering are the main problems necessitating artificial means to break dormancy. In South Africa (SA), most apple production areas receive insufficient winter chilling, and an annual application of rest breaking (RB) agents is included as standard practice. The most used RB agent in SA was dinitro-o-cresol (DNOC) but its use was discontinued. Hydrogen cyanamide (HC) became the replacement. It has been effective in apple, but variable effects on fruit set, blossom, yield and fruit quality have been reported. Thidiazuron (TDZ) has also shown the ability to break dormancy in apples. Another important practice in apple production is chemical thinning (CT). However, results are highly influenced by the type of chemical, weather conditions, cultivar and blossom pattern.

With the increasing efficacy of RB and by identifying its effects on vegetative and reproductive development, it will be possible to determine more effective chemical thinning treatments. The objective of this study was to determine appropriate RB treatments for apple trees in a warm winter climate, identifying their effect on vegetative and reproductive development and the influence on CT efficacy. The research was performed in the Elgin area (34°S, 300 m) SA, over a period of three years, on 'Golden Delicious' and 'Royal Gala'.

In evaluating the effect of different HC concentrations and oil, no synergistic or antagonistic effects were observed on budburst and yield. Mineral oil at 4% plus 1 to 2% Dormex[®] combined were sufficient to break dormancy. Dormex[®] at 4% (2.08% HC) reduced fruit set and yield. In general, the rest breaking treatments (DNOC, HC and TDZ) enhanced the final vegetative bud burst compared to the control, while reproductive bud burst in 2002 and 2003 was not significantly influenced. The treatments compressed and advanced flowering periods, but this effect was not always evident when the spring was warm. The treatments synchronised flowering on the tree and between the two cultivars. The mixture of 0.245% HC and 4% oil was less effective in terms of increasing bud burst in 'Royal Gala' compared to other rest-breaking treatments. The mixture of 0.49% HC and 4% oil effectively compressed and synchronised flowering in 'Golden Delicious'. TDZ-oil used at the lower rates also increased bud burst and concentrated flowering. However, it

appears that after a cooler winter, higher rates could result in an exacerbated bud burst effect with excessive vegetative growth.

The rate and timing of TDZ-oil application influenced the reproductive development of apples and therefore fruit quality. In 'Golden Delicious' increased fruit set, number of seeds, and reduced fruit russeting appear as beneficial results of TDZ-oil, whereas fruit set and russeting was not affected in 'Granny Smith'. TDZ-oil, when applied late and at increasing rates, led to an increase in the malformation of calyx cavities, especially when chemical thinning was performed using the cytokinin-like compound benzyladenine. The effect seemed to be cultivar specific, with 'Golden Delicious' being the most severely affected. Increased return bloom in response to late TDZ application in 'Golden Delicious' and 'Royal Gala' appeared to be beneficial.

OPSOMMING

EFFEK VAN CHEMIESE RUSBREEK- EN VRUGUITDUNBEHANDELINGS OP REPRODUKTIEWE ONTWIKKELING IN APPELBOME

'n Gebrek aan winterkoue is 'n ernstige probleem in warm produksie-areas wanneer gematigde sone vrugsoorte verbou word. Vertraagde bot en 'n uitgerekte bot- en blompatroon is van die grootste probleme. Dit noodsaak die gebruik van tegnieke om die gebrek aan winterkoue te probeer oorkom. In Suid-Afrika (SA) akkumuleer die meeste appelproduksie-areas te min winterkoue om dormansie natuurlik op te hef en is 'n jaarlikse aanwending van chemiese rusbrekers 'n standaard praktyk in kommersiële boorde. Die mees algemene rusbreker (RB) wat in Suid-Afrika gebruik is was dinitro-o-cresol (DNOC), maar dit is intussen van die mark onttrek. Waterstofsianimid (WS) het DNOC vervang. WS is effektief om die dormansie van appelknoppe op te hef, maar verskille in effektiwiteit t.o.v. opbrengs, vrugkwaliteit, vrugset en blomperiode is waargeneem. Thiadiazuron (TDZ) is ook effektief om die dormansie van appelknoppe op te hef. 'n Ander belangrike praktyk in appelboorde is chemiese uitdun (CU). Die uiteindelige resultaat van CU word grootliks deur die spesifieke middel, weerstoestand, cultivar en blompatroon en –intensiteit bepaal.

Met 'n toename in effektiwiteit van RB en deur die effek op vegetatiewe en reprodktiewe ontwikkeling te identifiseer, sal dit moontlik wees om meer effektiewe behandelings te ontwikkel. Die doel van hierdie studie was om die regte RB behandeling vir appelbome in 'n warm winter klimaat vas te stel, die effek op vegetatiewe en reprodktiewe ontwikkeling te identifiseer en die effek op CU te bepaal. Die navorsing is in die Elgin area (34°S, 300 m) SA oor 'n periode van drie jaar op 'Golden Delicious' en 'Royal Gala' uitgevoer.

Geen sinergistiese of antagonistiese effekte is waargeneem op knopbreek of opbrengs met die kombinasie van verskillende vlakke van HC en olie nie. Mineral olie teen 4%, in kombinasie met 1 tot 2 % Dormex® was genoeg om dormansie te oorkom. Dormex® teen 4% (2.08% HC) het vrugset en opbrengs verminder. Oor die algemeen het RB behandelings (DNOC, HC en TDZ) die finale vegetatiewe knopbreek verhoog in vergelyking met die kontrole, terwyl reprodktiewe knopbreek in 2002 en 2003 nie betekenisvol beïnvloed is nie. Die behandelings het die blomperiode verkort en vervroeg, maar die effek is nie altyd waargeneem indien die lente warm was nie. Die behandelings het tot sinkronisasie van blom in die boom en tussen die twee cultivars gelei. Die mengsel van 0.245% HC en 4% olie was minder effektief ten opsigte van knopbreek in 'Royal Gala' as ander RB behandelings. Die mengsel van 0.49% HC en 4% olie het die blomperiode in

‘Golden Delicious’ effektief gesinkroniseer en verkort. TDZ-olie teen laer dosisse het ook knopbreek verbeter en blom gekonsentreer. Dit wil egter voorkom dat, na ‘n koeler winter, die hoër dosisse oordrewe knopbreek en vegetatiewe groei tot gevolg het.

Die dosis en tyd van TDZ-olie toediening beïnvloed die reprodktiewe ontwikkeling van appels en dus vrugkwaliteit. In ‘Golden Delicious’ is verhoogde vrugset, saad getalle en verlaagde vrugverruwing as positiewe respons op TDZ-olie behandelings waargeneem, terwyl vrugset en verruwing nie in ‘Granny Smith’ geaffekteer is nie. Indien TDZ-olie laat aangewend word verhoog dit die ontwikkeling van kelk-end misvormdheid, veral wanneer dit in kombinasie met sitokinien-tipe chemiese uitdunmiddels soos benzieladenien gebruik word. Die effek is skynbaar cultivar spesifiek met ‘Golden Delicious’ die mees sensitiewe cultivar. ‘n Toename in opvolg-blom na TDZ toedienings is in ‘Golden Delicious’ en ‘Royal Gala’ waargeneem.

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This dissertation presents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters, therefore, has been unavoidable. The different styles used in this dissertation are in accordance with the agreements of different journals used for submission of manuscripts from the dissertation.

The first paper has already been published in the *S. Afr. J. Plant Soil* 22(4):251-256

GENERAL INTRODUCTION

The marketing of apples is becoming more and more difficult due to global overproduction. This results in an ever-increasing pressure on producers to improve fruit quality, especially fruit size. Orchard practices are focussed on increasing yield and fruit quality to reach a profitable production.

Apple is the most important deciduous fruit crop in the Western Cape Province of South Africa. There are four major production areas, Elgin (34°S, 305 m), Koue Bokkeveld (33°S, 945 m), Langkloof (33°S, 722 m) and Vyeboom (34°S, 309 m). These areas as the others in South Africa, have a relatively warm climate, which makes them marginal for apple production, because winter is not cold enough to satisfy chilling requirements. Low winter chilling and fluctuations in temperature with relatively warm days interspersed with colder days occur and cold accumulation is extended towards the end of winter and spring.

Chilling requirements are associated with endo-dormancy completion. Growth only recommences in spring after the trees had been subjected to a long period of cold that satisfies the chilling requirements (Saure, 1985; Faust *et al.*, 1997). Dormancy in temperate-zone deciduous fruit trees is a phase of development that allows the trees to survive unfavourable conditions during the winter (Saure, 1985). Fuchigami and Nee (1987) provided evidence that the depth of dormancy changes during the dormant period. In this regard, many terminology has been proposed to describe phases or stages of dormancy (Saure, 1985; Lang *et al.*, 1987; Lang, 1987). The more commonly used terminology to describe dormancy is that proposed by Lang *et al.* (1987) which classify dormancy into para-dormancy equated to correlative inhibition, endo-dormancy related to deep dormancy where dormancy causing factors reside within the bud, and eco-dormancy where dormancy is imposed by temperatures or other conditions unfavourable for growth.

In warm climate areas, winters are often not cold enough to satisfy the chill requirements of the trees before warm spring weather is experienced. The symptom called prolonged dormancy or delayed foliation may occur (Saure, 1985). Poor bud break will occur typically characterized by an earlier break of the terminal buds, scattered non-uniform bloom and lateral leafing (Erez, 2000).

Although much progress has been made in the area of breeding and selecting new low-chilling cultivars, the need for artificial means to break dormancy is still evident. Physical and chemical treatments have been evaluated as a means to compensate for insufficient chilling (Saure, 1985; Erez, 1987; Erez, 1995). In South Africa, most commercial orchards use chemical rest-breaking

agents to compensate for the lack of chilling and therefore to reduce delayed defoliation (Strydom and Honeyborne, 1971). A combination of dinitro-o-cresol (DNOC) with mineral oil was the standard practice used before to break dormancy. However, due to environmental and health considerations the use of DNOC was recently discontinued. In South Africa it has been mainly replaced by mixtures of hydrogen cyanamide (HC) and oil (North, 1992; North, 1993), though variable effects on yield, fruit quality, fruit set and blooming period have been observed (Erez, 1987; North, 1989; North, 1993; Jackson and Bepete, 1995; Erez, 2000). The use of HC is restricted mainly due to human sensitivity problems, thus the search for bud break promoters continues. Thidiazuron (TDZ) showed the capacity to release lateral buds from dormancy in apple buds (Wang *et al.*, 1986; Wang *et al.*, 1987) and also it reduced the number of chilling units required to achieve bud-break (Faust *et al.*, 1991). A mixture of TDZ with oil was recently introduced into South Africa as an alternative to increase bud burst.

Reproductive buds are more sensitive than vegetative buds to most of the dormancy breaking chemicals, and this sensitivity is manifested in flower bud phytotoxicity and loss of flowers (Erez, 2000). Detrimental effects of rest-breaking treatments in fruit set and yield could be due to increased vegetative growth that increases competition (Erez *et al.*, 2000), but also due to a phytotoxic effect on flower buds (Nee and Fuchigami, 1992; George and Nissen, 1993). The time and concentration of the rest-breaking treatment influences the bud break response of vegetative and reproductive buds (Saure, 1985; Erez, 1987; Lee, 1994). This may result in differences in flowering pattern and synchronisation of reproductive and vegetative growth. However, there is not enough information available in this regard. Research has determined the optimum combination of oil and HC for dormancy release in apple. However, reducing the amount of HC reduces cost. The extent to which an increase in oil concentration can reduce the use of HC is unknown. On the other hand, insufficient information is available on how TDZ in combination with oil affects flowering pattern, yield and fruit set of apple trees in marginal climatic production areas such as those in South Africa.

Another critical part in the production of apples of good size and quality is chemical thinning of flowers and/or fruitlets (Williams, 1979; Link, 2000). Since thinning can be performed mechanically or chemically, thinning intensity may vary not only on the method used, but also on the physiological condition of the trees and cultural practices employed (Link, 2000). Since rest-breaking agents influence bud break and full bloom date in warm climates (Jackson and Bepete,

1995) but also flowering pattern (Bound and Jones, 2004), the responsiveness of flowers and fruitlets thinning would be influenced by the rest-breaking treatment.

Increasing the efficacy of the rest breaking treatments and identifying their effects on vegetative and reproductive development, it will be possible to determine more effective chemical thinning treatments, resulting in increased fruit size.

The objective of this study was to determine appropriate rest-breaking treatments for apple trees in warm climate identifying their effect on bud burst, flowering pattern, fruit set, yield and fruit quality, and the influence of these treatments on chemical thinning efficacy.

Literature Cited

- Bound, S.A. and Jones, K.M., 2004. Hydrogen cyanamide impacts on flowering, crop load, and fruit quality of red 'Fuji' apple (*Malus domestica*). *New Zealand Journal of Crop and Horticultural Science* 32: 227-234.
- Erez, A., 1987. Chemical control of budbreak. *HortScience* 22: 1240-1243.
- Erez, A., 1995. Means to compensate for insufficient chilling to improve bloom and leafing. *Acta Horticulturae* 395: 81-95.
- Erez, A. 2000. Bud dormancy; phenomenon, problems and solutions in the tropics and subtropic. In: Erez, A. (Ed.), *Temperate fruit crops in warm climate*, pp. 17-48. Bet-Dagan: Kluwer Academic Publishers. 48 pp.
- Erez, A., Yablowitz, Z. and Korcinski, R., 2000. Temperature and chemical effects on competing sinks in peach bud break. *Acta Horticulturae* 514: 51-58.
- Faust, M., Erez, A., Rowland, L.J., Wang, S.Y. and Norman, H.A., 1997. Bud dormancy in perennial fruit trees: physiological basis for dormancy induction, maintenance, and release. *HortScience* 32: 623-629.
- Faust, M., Millard, M.M. and Stutte, G.W., 1991. Bound versus free water in dormant apple buds-a theory for endodormancy. *HortScience* 26: 887-890.
- Fuchigami, L.H. and Nee, C.C., 1987. Degree growth stage model and rest-breaking mechanism in temperate woody perennials. *HortScience* 22: 836-845.
- George, A.P. and Nissen, R.J., 1993. Effect on growth regulants on defoliation, flowering, and fruit maturity of the low chilling peach cultivar Flordaprince in subtropical Australia. *Australian Journal of Experimental Agriculture* 33: 787-795.

- Jackson, J.E. and Bepete, M., 1995. The effect of hydrogen cyanamide (Dormex) on flowering and cropping of different apple cultivars under tropical conditions of sub-optimal winter chilling. *Scientia Horticulturae* 60: 293-304.
- Lang, G.A., 1987. Dormancy: a new universal terminology. *HortScience* 22: 817-820.
- Lang, G.A., Early, J.D., Martin, G.C. and Darnell, R.L., 1987. Endo-, para-, and eco-dormancy physiological terminology and classification for dormancy research. *HortScience* 22: 371-377.
- Lee, R.R., 1994. Interrelationships between flowering habit, fruit characteristics, hydrogen cyanamide applications, and xylem cytokinin levels in 'Rome Beauty' apples (*Malus domestica* Bork.). University of Idaho.
- Link, H., 2000. Significance of flower and fruit thinning on fruit quality. *Plant Growth Regulation* 31: 17-26.
- Nee, C.C. and Fuchigami, L.H., 1992. Overcoming rest at different growth stages with hydrogen cyanamide. *Scientia Horticulturae* 50: 107-113.
- North, M., 1989. Effect of cyanamide and DNOC/oil on budbreak, yield and fruit size of Golden Delicious apples. *South African Journal of Plant and Soil* 6: 176-178.
- North, M., 1992. Alternative rest-breaking agent for apples. *South African Journal of Plant and Soil* 9: 39-40.
- North, M., 1993. Effect of application date on the rest-breaking action of cyanamide on 'Golden Delicious' apples. *Deciduous Fruit Grower* 43: 470-472.
- Saure, M.C., 1985. Dormancy release in deciduous fruit trees. *Horticultural Reviews* 7: 239-300.
- Strydom, D.K. and Honeyborne, G.E., 1971. Delayed foliation of pome and stone fruits. *Deciduous Fruit Grower* 21: 126-129.
- Wang, S.Y., Ji, Z.L., Sun, T. and Faust, M., 1987. Effect of thidiazuron on abscisic acid content in apple bud relative to dormancy. *Physiologia Plantarum* 71: 105-109.
- Wang, S.Y., Steffens G.L. and Faust, M., 1986. Breaking bud dormancy in apple with a plant bioregulator, thidiazuron. *Phytochemistry* 25: 311-317.
- Williams, M.W., 1979. Chemical thinning of apples. *Horticultural Reviews* 1: 270-300.

LITERATURE REVIEW

1. Introduction

Temperate-zone fruit trees survive throughout successive unfavourable winters, during which they produce no visible growth, even under suitable conditions. This state is called winter dormancy. This stage is induced naturally in late summer and fall and is broken by low temperatures during fall and winter. Temperature is the main factor that affects dormancy release. Fulfilment of the chilling requirement is necessary for deciduous fruit trees to end dormancy and to successfully flower and produce fruit (Samish, 1954; Saure, 1985; Erez, 1987). The amount of chilling required depends upon the fruit type, species and cultivar (Samish, 1954; Saure, 1985; Hauagge and Cummins, 1991a; Erez, 2000).

Deciduous fruit tree production in warm climates face the problem of inadequate winter chilling to satisfy the chill requirements for dormancy release. Under these conditions delayed foliation may occur (Saure, 1985) characterised by a series of related aberrations in the reproductive and vegetative development, such as protracted and poor foliage development and bloom. To overcome these problems and to normalise budburst, the use of rest-breaking agents is essential in production areas with inadequate winter chilling. The effect of these chemicals differ depending on the local conditions and type of chemical, and varied effects may be expected depending on the amount of chilling that is lacking. In this sense, variation in blossom intensity and blossom period could modify the need for fruit thinning to ensure good yield and fruit quality (Williams, 1979; Byers *et al.*, 1990; Ferree, 1996).

Literature relating to dormancy, rest-breaking agents and chemical thinning effects on deciduous fruit trees, with emphasis on apples grown in mild climates, is briefly summarised in this literature review. These are very broad topics and many extensive reviews on these topics already exist and it will not be attempted to rewrite these.

2. Dormancy in deciduous fruit trees

Dormancy is used as a general term to indicate a period of temporary suspension of visible growth of a plant structure containing a meristem (Lang, 1987). This is a practical definition which in the case of buds includes those that are growing very slowly, such as fruit buds in winter (Faust, 1989;

Faust *et al.*, 1995b), and axillary 'trace buds' which may persist for years under the bark while growing just enough each year for the tip to keep pace with cambial growth (Esau, 1965).

The length of the bud dormancy period under field conditions varies among cultivars, wild species, and interspecific hybrids (Faust, 1989; Crabbé and Barnola, 1996). Entry into dormancy and emergence from it are therefore likely to involve mechanisms relevant to the conditions under which the particular plant genotype evolved. Hauagge and Cummins (1991b) showed that low chilling cultivars definitely have a different pattern and depth of dormancy than those with high chill requirements.

Saure (1985) proposed terminology to explain three stages of dormancy, pre-, true-, and imposed-dormancy. Lang *et al.* (1987) also classified three stages of bud dormancy, viz., para-, endo- or eco-dormancy, which correspond to those terms proposed by Saure (1985). Apple bud dormancy in temperate regions can be explained through these phases. In summer and early autumn the primary mechanism controlling bud dormancy is correlative inhibition or apical dominance and the buds are classified as para-dormant (Lang, 1987). At this time buds can be stimulated to grow out quickly if the source of the correlative inhibition is removed, either in the field when temperatures are suitable for growth or under so-called forcing conditions when cut shoots are kept at adequate temperatures with their bases in water. In late autumn and early winter, buds progress into a state of dormancy called endo-dormancy, deep dormancy, true dormancy or rest where the inhibition of growth is by internal bud signals (Saure, 1985; Lang *et al.*, 1987; Faust *et al.*, 1997). Following exposure to a period of low temperatures, the buds lose their endo-dormancy and can be induced into rapid bud-break under forcing conditions (Faust *et al.*, 1997; Erez, 2000). Dormancy in the field is maintained by low temperature. This period of eco-dormancy lasts until the buds have been exposed to enough high temperature to attain bud break (Saure, 1985; Lang *et al.*, 1987; Faust *et al.*, 1997).

Although the dormancy phases are usually thought of as occurring separately, any given bud may be simultaneously controlled by any, or all of the signals regulating these aspects of dormancy (Horvath *et al.*, 2003). Detailed studies have shown that the three types of dormancy interact, overlap in time, and may have mechanisms in common (Jackson, 2003; Tromp, 2005). The main characteristic of winter dormancy is that once the buds become endo-dormant, no artificial treatments can fully replace the chilling required to normalise bud burst; there is a compensation for only part of the actual chilling requirement, and it can be obtained only after the buds had been exposed to partial chilling (Erez, 2000).

In mature apple trees, bud formation and dormancy intensification start early in the summer (Hauagge and Cummins, 1991b). In temperate climates, terminal buds of apple shoots rapidly enter dormancy in autumn and then start to exit dormancy initially slowly but more rapidly in late winter before spring budburst (Cook *et al.*, 1998a). Maximum dormancy intensity occurs after low temperatures are observed in the field (Hauagge and Cummins, 1991b), and low temperature plays a role in the development of the maximum dormancy intensity. At warmer temperatures, apple trees take longer to enter into and exit from dormancy (Cook and Jacobs, 2000).

During dormancy buds develop as isolated entities, they lose their normal interconnections as xylem and phloem movement are extremely reduced and even plasmodesmata are disrupted between the meristem and surrounding tissues (Van der Schoot, 1996). It is generally accepted that not all buds on a tree have similar chill requirements, and each behave individually, but not independently (Saure, 1985). Normally, flower buds have a lower chill requirement than vegetative buds, and terminal vegetative buds have a lower chill requirements than lateral ones (Samish and Lavee, 1962, cit. Saure, 1985). Even among the lateral leaf buds there may be noticeable differences, depending on the section on the shoot to which they belong (Faust *et al.*, 1995a; Crabbé, 1984; Cook *et al.*, 1998b). The position within the tree and the vigour of the shoot, among others, are also mentioned as factors influencing chilling requirements (Saure, 1985). Extended chilling, however, does tend to normalise these differences (Cook *et al.*, 1998a). Therefore, the different phases overlap in a tree, which is more noticeable under lack of winter chilling conditions.

One of the main subjects that dormancy studies centered around was the linear hormonal hypothesis, which considers a change in the balance between promoters and inhibitors to impose and break dormancy. Faust *et al.* (1997) discuss the theory that suggests multifaceted control of dormancy, where four major biological factors that possibly change the intensity of dormancy can be identified. They are hormone balance in the bud or in the tree, state of water within the bud, structure of membranes, and anabolic potential of the buds. Studies in this regard suggest that the processes are complex and interrelated. Many researchers investigated metabolic changes in the search of the variables and characteristics related to environmental conditions such as chilling accumulation (Seeley and Powell, 1981; Wood, 1983; Wang *et al.*, 1985; Champagnat and Côme, 1986; Powell, 1987; Wang *et al.*, 1987; Wang and Faust, 1990; Bubán and Faust, 1995; Yung *et al.*, 1995; Faust *et al.*, 1997; Bonhomme *et al.*, 1997; Arora *et al.*, 1997; Rowland and Arora, 1997; Arora *et al.*, 2003; Zanol and Bartolini, 2003).

Most advancements regarding the mechanism involved in bud dormancy induction and release at the subcellular level (e.g. biochemical pathways and signals, dormancy from cold acclimation, biochemistry of dormancy mutants, hormonal physiology) and the genetics of dormancy in woody plants have only been made in the last 10 to 20 years (Arora *et al.*, 2003). Another approach has been the study of molecular events involved in the perception and transduction of dormancy breaking signals during chemical induced dormancy release in grapes (Or *et al.*, 2002).

After dormancy has been completed, buds need to be exposed to a period of warmer temperature to be able to burst. This is measured as heat units or growing degree hours (GDH°C) (Richardson *et al.*, 1974). This can be expressed as two temperature-dependent processes: a) the accumulation of chilling to the level required for dormancy completion; and b) the accumulation of the heat units required for the buds to develop to bloom and foliation (Naor *et al.*, 2003). These two processes are interdependent; the need for heat exposure for bud burst is reduced by increased chilling accumulation (Shaltout and Unrath, 1983; Couvillon and Erez, 1985; Powell, 1986).

2.1 Chilling requirements

The chilling requirement to break dormancy is not a constant factor, especially in mild winter conditions characterised by a shorter period at low temperature, but also by wide temperature fluctuations during the dormancy. Erez *et al.* (1979) working on peach leaf buds, found that the effect of exposure to chilling for short periods was rapidly cancelled during subsequent exposure to higher temperatures. However, with longer chilling periods the chilling effect was not cancelled by higher temperature. Erez and Couvillon (1987) found that the longer the period of high temperature, the higher the negation effect. The effectiveness of the negation reaction also varies throughout the dormancy period. It was found to be most effective early in dormancy, if the warm period exceeded 7 days. The negating effect of the high temperatures decreases as the dormancy progresses (Erez and Couvillon, 1987).

It was determined that 6°C contributed more to rest completion than 3°, 8° and 10°C in peaches (Erez and Lavee, 1971; Erez *et al.*, 1979). Naor *et al.* (2003) studied chilling requirements of vegetative buds under controlled condition on whole apple trees. Trees that were exposed to 8 hours of alternating high temperatures (>14 °C) had lower levels of bud break, 2°C was the most efficient temperature, with reduced efficiency at higher temperatures (76% at 6°C and 39% at 10°C) (Naor *et al.*, 2003). Their data suggest that vegetative buds of apples are more responsive to low temperatures than those of peach (Richardson *et al.*, 1974; Erez and Couvillon, 1987).

The response of deciduous fruit trees to winter chilling influences three parameters, viz., the level, the time and the uniformity of bud break (Erez, 1995). Limited information is available regarding the effect of temperature on dormancy completion of apple buds under different climatic conditions. Quantitative models of buds dormancy include the use of chill unit accumulation (CU) to describe specific phenological events and the determination of end points of dormancy (Weinberger, 1950; Richardson *et al.*, 1974; Shaltout and Unrath, 1983; Linsley-Noakes *et al.*, 1994; Fuchigami and Wisniewski, 1997).

The number of hours below 7.2°C before bud break occurs is frequently used as a measure of CU (Weinberger, 1950; Linsley-Noakes *et al.*, 1994). The Utah model (Richardson *et al.*, 1974) assigns weighted values to different temperatures, where CU accumulate only between 1.5 and 12.4°C and not at lower temperatures. At temperatures higher than 15.9°C, chilling negation is supposed to occur; therefore, a negative accumulation is counted, where a maximum negative effect (-1 CU) is assigned to temperatures > 18°C. A chill model developed for 'Sungold' nectarine, called the Florida Model (Gilreath and Buchanan, 1981), also proposes a range of effective temperatures. Accumulation occurs between 1.8°C and 14°C, chilling negation (-0,5 CU) is supposed to occurs when temperatures are higher than $\geq 19,5$ °C, and assigns a greater negative effect (-1 CU) to temperatures exceeding 21,5°C (Gilreath and Buchanan, 1981). Another chill model developed for 'Starkrimson Delicious', the North Carolina Model, proposes a range of effective temperature (1,6 and 13 °C), chilling negation occurs when temperatures are higher than 19 °C, and assigns a greater negative effect (-2 CU) to temperatures equal or exceeding 23.3°C (Shaltout and Unrath, 1983). The dynamic model adds a further element, which is the timing of exposure to temperature in a cycle (Erez *et al.*, 1979; Fishman *et al.*, 1987). This model not only takes into account the negative effect of high day temperatures, but also recognises the positive effect of moderate temperatures in the chilling cycle. Linsley-Noakes *et al.* (1994) proposed a modification to the Utah model for South African conditions. This model assumes that the negation effect of temperatures above 15.9 °C is confined to the diurnal cycle and should not be accumulated from one day to the next. This model has been called "modified Utah chill units" (Linsley-Noakes *et al.*, 1994), "positive daily Richardson Units" (Allan *et al.*, 1995), and "daily positive Utah Chill units model" (Linsley-Noakes *et al.*, 1995). In South Africa, currently, three monitoring systems for chill accumulation are used: Utah or Richardson model, the 'modified' chilling model and the hours below 7.2°C. Hauagge and Cummins (1991a) estimated chilling requirements to break dormancy from field chilled shoots, and found 1064 ± 61 NC units for 'Gala' and 1050 ± 15 for 'Golden Delicious' apples, as an average of three seasons, to be optimum.

2.2 Artificial means to break dormancy

Many chemicals have been tested for dormancy-breaking activity, such as dinitro compounds, oils, cyanamides, potassium nitrates, thioureas and growth regulators (Samish, 1954; Erez, 1979; Saure, 1985; Erez and Couvillon, 1987; Erez, 2000), but only a few have been effective for field treatments and have been used in commercial orchards. The active chemicals have no common characteristic except that many of them are effective at rates very near to the lethal point (Saure, 1985; Erez, 1987; Erez, 2000).

Oil was the first chemical used to break dormancy. However, its effect is mild and it needs to be applied in combination with other chemicals to enhance the dormancy breaking effect (Samish, 1954; Erez and Zur, 1981; Honeyborne and Rabe, 1993). In combination with dinitro-*o*-cresol (DNOC) it gained acceptance since the middle of the previous century (Samish, 1954; Erez and Zur, 1981). However, due to environmental and health considerations the use of DNOC was recently discontinued.

Other products including calcium cyanamide, thiourea, and KNO_3 , proved to be effective in breaking dormancy but less so than DNOC (Erez *et al.*, 1971; Erez, 1995). The rest-breaking properties of hydrogen cyanamide (HC) were evaluated in several species since the 1980s, but only later in apples. HC alone, and in combination with mineral oil, has shown positive results in apple trees (North, 1989; Petri and Stuker, 1995). HC at 1.25% + oil at 3%, and 5% DNOC-oil gave similar bud burst and fruit set on four-year-old 'Golden Delicious' trees in South Africa (North, 1992). Research has determined the optimum combination of oil and HC for dormancy release in apple. Reducing the amount of HC will reduce cost; however, the extent to which an increase in oil concentration can reduce the use of HC is unknown.

Although HC effectiveness on apple tree dormancy release has been widely confirmed, discrepancies have been shown in terms of yield, fruit quality, fruit set and blooming period. Under insufficient winter chilling conditions, lack of blossom synchronisation of different cultivars has been reported (Jackson and Bepete, 1995). In Egypt, Dormex[®] at 3% (1.49% HC) significantly reduced the ultimate fruit retention of 'Dorsett Golden' compared to untreated control (El-Kassas *et al.*, 1996). On the other hand, North (1989) found that HC at 2.5% increased fruit set significantly relative to the untreated control in 'Golden Delicious' apples. HC at 3% has also been tested on fully chilled 'Fuji' apple and advanced flowering, full bloom was advanced by more than one week and the flowering period from pink bud to full bloom compressed; however it reduced

fruit set in the first year, but not the second (Bound and Jones, 2004). Application of 2.5% HC six weeks before bloom reduced terminal blossom numbers in two years, and synchronised bloom by delaying terminal bloom (Lee, 1994). The main cause for the variable results appears to reside in the level of endo-dormancy of the buds. Resistance to the phytotoxic effect of the chemical declines rapidly, following endo-dormancy release (Erez, 2000). Damage to flower buds has been reported for various species (Nee and Fuchigami, 1992; George and Nissen, 1993; Williamson *et al.*, 2002).

HC has a restricted use mainly due to human sensitivity problems, thus the search for bud break promoters that are as effective as HC continues. The cytokinin, 6-benzylamine purine (BA), has been used to increase vegetative bud break in apple (Krisanapook *et al.*, 1990). Other cytokinin analogs, especially 1-phenyl-3-(1,2,3-thiadiazol-5-yl)urea (thidiazuron; TDZ), have been used to overcome dormancy (Wang *et al.*, 1986; Steffens and Stutte, 1989; Petri *et al.*, 2001). TDZ and other chemicals that increase cytokinin concentrations in the xylem sap are not equally effective in breaking dormancy during the entire dormant period. Some are able to trigger growth in late autumn and again when about two-thirds to three-fourths of the chilling requirement of buds is satisfied (Erez, 1987; Steffens and Stutte, 1989). However, in a more recent study, George *et al.* (2002) could compensate for nearly 50 % of chilling for the low chilling requirement 'Springbrite' nectarine, either using a mix of fatty acid esters (Waken[®]) or one alkylated amine (Armobreak[®]) combined with potassium nitrate. Similar results in terms of bud break were obtained when GA₃ or Dormex[®] were used. TDZ has the capacity to release lateral buds from dormancy (Wang *et al.*, 1986) and also it reduces the number of chilling units required to achieve bud break (Steffens and Stutte, 1989; Faust *et al.*, 1991). Alvarado-Raya *et al.* (2000) proved that TDZ at three concentrations (50, 100 and 200 mg·L⁻¹) was as effective as Dormex[®] at 5 mL·L⁻¹ in advancing the beginning of flowering and full bloom, and reducing the time between these two stages in 'Shiro' plum. TDZ applied at a concentration of 100 mg·L⁻¹, 17 days before full bloom, increased the ovary diameter and the thickness of the ovary wall in the flower bud.

When trees resume growth during spring, their metabolism changes. The apparently dormant buds suddenly become active and visible growth occurs. Some events, associated with resumption of growth, such as cell division, are obvious, other are more subtle (Faust and Wang, 1993). It is difficult to discern the early events when growth is resumed because visible signs of growth occur only several days after metabolic changes are initiated (Faust and Wang, 1993). Cytokinins increase in the xylem sap of apple just prior to bud break (Cutting *et al.*, 1991; Tromp and Ovaas, 1990). Within 48 hours after treatment with TDZ on dormant apple buds in summer, changes in the

bud are clearly visible with MRI (magnetic resonance imaging). Water moves into the bud, water is relatively free compared to its pretreatment bound state, and the embryonic axis of the bud become swollen (Liu *et al.*, 1992). Changes in respiratory metabolism is marked during the first 8 days after application. Both catalase activity and the number of isoenzymic components of catalase increased immediately after TDZ induced bud break (Faust and Wang, 1993). Nir *et al.* (1986) found a reduction in catalase activity in response to thiourea and cyanamide treatments. Or *et al.* (2002), suggest that kinase might be involved in perception of stress signal induced by HC in grapes buds. They suggest a biochemical identity of the signal to be a transient disruption of respiratory metabolism caused by hydrogen peroxide, generated by HC-induced oxidative stress, an explanation supported by their observations on the complete shut down of catalase gene expression soon after HC application.

In general, chemical rest-breaking may advance and/or concentrate flowering (Erez, 1987; Lee, 1994; Jackson, 2000; Alvarado-Raya *et al.*, 2000; Bound and Jones, 2004), and advance leafing resulting in potential competition between vegetative and reproductive development (Erez *et al.*, 2000). As a result, the conditions for others cultural practices could be affected.

3. Flower bud initiation

Some cultivars produce a significant part of their crop from terminal and lateral buds on long shoots that developed the previous season. This is especially true for young trees, highly vigorous trees, and trees in certain very intensive management systems (Forshey and Elfving, 1989). Flower induction on the current seasons' shoots occurs after mid-summer and after extension growth has ceased (Luckwill, 1974). However, most commercially important cultivars produce mainly on spurs. Flower induction on spurs occurs three to six weeks after full bloom (Buban and Faust, 1982). However, flower induction may be delayed if the trees are bearing a heavy crop or are highly vigorous (Forshey and Elfving, 1989).

Flower bud formation in bearing trees is fundamentally determined by the presence of hormones (Buban, 1996). The failure of flower initiation in trees carrying a heavy crop of fruit which, in the past was attributed directly to the effect of the crop in depleting the carbohydrate and nitrogenous reserves of the tree is widely recognized to be due to hormonal rather than nutritional causes (Luckwill, 1974).

The most recognised inhibition of floral induction is that exerted by fruit containing seed (Chan and Cain, 1967) and vigorously growing shoots (Buban and Faust, 1982). The effect of these inhibitions is expressed in alternate bearing (Buban, 2003). It has been proved that in apples an increased vegetative growth is negatively correlated (-0,74 to -0,95) to flower formation (Jones *et al.*, 1989). On the other hand, treatments with ethephon (ethylene generator) enhance apple tree bloom density without a reduction in shoot growth or fruit thinning (Schmidt *et al.*, 1975, cit. Buban, 2003). The site of the source of inhibition (fruit with seeds and shoot apices) are remote to the site of flower initiation, hence, the transport of a signal is required (Bangerth, 1997). However, it is uncertain whether the signal arrives immediately from the seeded fruit or shoot tip to the site of inhibition or through other organs, e.g. leaves (Lavee, 1989).

Apple seed are a rich source of gibberellins (GAs) and their translocation into the plant can inhibit the formation of flowers (Chan and Cain, 1967). GAs begin appearing in the seeds four to five weeks after bloom (Buban, 1996). As GAs stimulate the release of indole acetic acid (IAA) from the fruit, IAA may be considered as an alternative to GAs, i.e. as a signal responsible for inhibiting flower initiation. In that sense, the inhibition of flowering by GAs would rather be an indirect effect which is successful in stimulating IAA synthesis at the emission site of the signal, in immature seeds (Bangerth, 1997). The auxin level of the seeds reaches a maximum four to five weeks after flowering (Luckwill, 1970, cit. Buban, 1996), followed by a second peak probably originating from the embryo seven weeks later.

4. Chemical thinning

Fruit thinning is the most important technique in apple cultivation for improving fruit quality (Looney, 1993). Since thinning can be performed mechanically or chemically, thinning intensity may vary not only due to the method used, but also due to the physiological condition of the trees and cultural practices employed. Chemical thinning is used widely in commercial apple production to increase size, enhance return bloom, improve quality, avoid limb breakage and lessen biennial bearing (Williams, 1979; Byers *et al.*, 1990; Ferree, 1996). For the fresh market, fruit size, appearance, flavour, firmness and storability are of main interest.

Chemicals used for thinning either prevent fruit set or increase the proportion of fruits that fall in the “June drop”; some, however, are effective even after this drop (Dennis, 2002). Since there are chemicals acting as blossom thinners and others as fruitlets thinners, application time is critical. Many factors affect the thinning effectiveness of a particular chemical (Williams, 1979; Dennis,

2000). The mechanism involved in blossom thinning is mainly caustic to prevent pollination, fertilisation, or both, or some of the flowers are injured, inducing their abscission (Dennis, 2002; Greene, 2002). The mechanisms involved in fruit thinning are more complex, in terms of effect of the applied chemicals on phloem transport, endogenous hormones content and biosynthesis, seed development and other physiological processes (Dennis, 2002). Chemical thinning in apples has been reviewed in many previous publications (e.g. Williams, 1979; Looney, 1986; Bangerth, 1986; Byers and Carbaugh, 1991; Dennis, 2000; Bangerth, 2000).

The most commonly used blossom thinner was DNOC until it was removed from the market. Monocarbamide dihydrogen sulfate has proved to be an effective blossom thinner on several apple cultivars (Fallahi *et al.*, 1997; Byes, 1997). The herbicide endothall has also thinning activity (Byes, 1997). Other potential blossom thinners include pelargonic acid, ammonium thiosulfate (ATS) (Byes, 1997) and hydrogen cyanamide (Fallahi *et al.*, 1992; Fallahi *et al.*, 1997). 1-naphthaleneacetic acid (NAA) is less frequently used as blossom thinner, but can also reduce fruit set (Jones *et al.*, 1992). Ethephon may also thin when applied at bloom (Jones *et al.*, 1990) or even several days earlier at the balloon stage (Jones *et al.*, 1983). The majority of thinning done commercially the past 50 years however is performed using post-bloom thinners. There is a comfort level for growers to delay applications until they have a better estimate of fruit set (Greene, 2002).

NAA and 1-naphthyl N-methylcarbamate (carbaryl) are effective fruit thinners for a period of 4 to 5 weeks after full bloom (Byers *et al.*, 1990; Byers and Carbaugh, 1991). 6-Benzyladenine (BA) has become an efficient agent to treat hard-to-thin apple cultivars (Elfving, 1989; Basak, 1996; Bound *et al.*, 1997). Greene *et al.* (1990) and Basak (1996) reported BA to be effective in increasing the fruit size even in the absence of a significant thinning effect. Other compounds with cytokinin activity (like forchlor-fenuron (CPPU) and thidiazuron (TDZ)) also provide the possibility to control fruit set (Greene, 1993).

Environmental conditions may strongly affect chemical thinning action (Williams, 1979; Link, 2000). Cool, cloudy wet periods preceding chemical thinning agents generally means that thinning will be easier (Williams, 1979). Part of this is attributed to epicuticular wax and cuticle development which predisposes leaves to absorb more of the chemical (Westwood *et al.*, 1960). These conditions during and immediately after bloom may also lead to less vigorous fruit set, characterised by fruit that are not growing vigorously and have few seeds, increased seed abortion, and reduced carbohydrates (Forshey, 1986, cit. Greene, 2002). The temperature following chemical

thinning agent application is also a dominant factor influencing the response to the application (Williams, 1994). Elevated temperatures provide the stress required for thinners to work (Williams, 1994). It is not uncommon to have several days of cloudy weather during the bloom period where incoming solar radiation is reduced to 10-15% of full sun. This shading can intensify “June drop” (Greene, 2002).

As most of these chemicals are sprayed at bloom or post-bloom (Greene, 1995), their efficacy could be affected by the effect of rest-breaking treatments on flowering, bloom and bud break pattern and fruit set.

Literature Cited

- Allan, P., Rufus, G., Linsley-Noakes, G.C. and Matthee, G.W., 1995. Winter chill models in a mild subtropical area and effects of constant 6°C chilling on peach budbreak. *Acta Horticulturae* 409: 9-17.
- Alvarado-Raya, H., Rodríguez-Alcázar, J., Calderón-Zavala, G. and Cárdenas-Zoriano, E., 2000. Thidiazuron, flower budbreak and ovary dimensions in japanese plum (*Prunus salicina* L.) 'Shiro'. *Agrociencia* 34: 321-327.
- Arora, R., Rowland, L. and Tanino, K., 2003. Induction and release of bud dormancy in woody perennials: a science comes of age. *HortScience* 38: 911-921.
- Arora, R., Wisniewski, M.E. and Rowland, L.J., 1997. Low temperature-induced expression of dehydrins in deciduous fruit crops and their relation to cold acclimation and/or dormancy. *Acta Horticulturae* 441: 175-182.
- Bangerth, F., 1986. Thinning of apple fruits and relations to endogenous hormones. *Acta Horticulturae* 179: 605-612.
- Bangerth, F., 1997. Can regulatory mechanism in fruit growth and development be elucidated through the study of endogenous hormone concentrations? *Acta Horticulturae* 463: 77-87.
- Bangerth, F., 2000. Abscission and thinning of young fruit and their regulation by plant hormones and bioregulators. *Plant Growth Regulation* 31: 43-59.
- Basak, A., 1996. Benzyladenine (BA) as an apple fruitlet thinning agent-preliminary results. *HortScience* 28: 54-57.
- Bonhomme, M., Rageau, R., Richard, J.P. and Gendraud, M., 1997. Dormancy of peach floral buds: biological and tentative biochemical approaches. *Acta Horticulturae* 441: 167-173.
- Bound, S.A. and Jones, K.M., 2004. Hydrogen cyanamide impacts on flowering, crop load, and fruit quality of red 'Fuji' apple (*Malus domestica*). *New Zealand Journal of Crop and Horticultural Science* 32: 227-234.

- Bound, S.A., Jones, K.M. and Oakford, M.J., 1997. Post-bloom thinning with 6-benzyladenine. *Acta Horticulturae* 463: 493-499.
- Buban, T. 1996. Flower bud development and formation of sexual organs. In: Nyéki, J. & Soltész, M. (Eds.), *Floral biology of temperate zone fruit trees and small fruits*, pp. 3-79. Budapest: 79 pp.
- Buban, T. 2003. Hormonal aspects of flower formation and fruit set. In: Kozma, P., Nyéki, J., Soltész, M. & Szabó, Z. (Eds.), *Floral biology, pollination and fertilisation in temperate zone fruit species and grape*, pp. 3-24. Hungary: 24 pp.
- Buban, T. and Faust, M., 1982. Flower bud induction in apple trees: Internal control and differentiation. *Horticultural Reviews* 4: 174-203.
- Bubán, T. and Faust, M., 1995. New aspects of bud dormancy in apple trees. *Acta Horticulturae* 395: 105-111.
- Byers, R.E., Barden, J.A. and Carbaugh, D.H., 1990. Thinning spur 'Delicious' apple by shade terbacil, carbaryl, and ethephon. *Journal of the American Society for Horticultural Science* 115: 9-13.
- Byers, R.E. and Carbaugh, D.H., 1991. Effect of chemical thinning sprays on apple fruit set. *HortTechnology* 1: 41-48.
- Byes, R.E., 1997. Effect of bloom-thinning chemicals on apple fruit set. *Journal of Tree Fruit Production* 2: 13-31.
- Champagnat, P. and Côme, D., 1986. Some thoughts on hormonal regulation of bud and seed dormancies. *Acta Horticulturae* 179: 117-127.
- Chan, B.G. and Cain, J.C., 1967. The effect of seed formation on subsequent flowering in apple. *Proceeding of the American Society for Horticultural Science* 91: 63-67.
- Cook, N.C. and Jacobs, G., 2000. Progression of apple (*Malus x domestica* Borkh.) bud dormancy in two mild winter climates. *Journal of Horticultural Science & Biotechnology* 75: 233-236.
- Cook, N.C., Rabe E, Keulemans, J. and Jacobs, G., 1998a. The expression of acrotony in deciduous fruit trees: a study of the apple rootstock M9. *Journal of the American Society for Horticultural Science* 123: 30-34.
- Cook, N.C., Rabe E. and Jacobs, G., 1998b. Some aspects of bud dormancy in Japanese plum (*Prunus salicina* Lindl.). *Journal of the Southern African Society for Horticultural Sciences* 8: 75-79.
- Couvillon, G.A. and Erez, A., 1985. Influence of prolonged exposure to chilling temperatures on bud break and heat requirement for bloom of several fruit species. *Journal of the American Pomological Society* 110: 47-50.
- Crabbé, J., 1984. Vegetative vigor control over location and fate of flower buds, in fruit trees. *Acta Horticulturae* 149: 55-63.
- Crabbé, J. & Barnola, P. 1996. A new conceptual approach to bud dormancy in woody plant. In: Lang, G.A. (Ed.), *Plant dormancy: physiology, biochemistry and molecular biology*, pp. 83-113. Cab International. 113 pp.

- Cutting, J.G.M., Strydom, D.K., Jacobs, G., Bellstedt, D.U., Merwe, K.J.v.d. and Weile, E.W., 1991. Changes in xylem constituents in response to rest-breaking agents applied to apple before budbreak. *Journal of the American Society for Horticultural Science* 116: 680-683.
- Dennis, F.G., 2002. Mechanism of action of apple thinning chemicals. *HortScience* 37: 471-474.
- Dennis, F.G.J., 2000. The history of chemical thinning. *Plant Growth Regulation* 31: 1-16.
- El-Kassas, S.E., El-Sese, M.A., El-Salhy, A.M. and El-Wasfy, M.M., 1996. Physiological studies on flowering, fruit setting and bearing habits of some apple cultivars under Assiut environment. *Assiut Journal of Agricultural Sciences* 27: 3-21(abstract).
- Elfving, D.C., 1989. N-(phenylmethyl)-1H-purine-6 amine (BA) as a chemical thinner for 'Idared' apple. *Acta Horticulturae* 239: 357-362.
- Erez, A., 1979. The effect of temperature on the activity of oil + dinitro-o-cresol sprays to break the rest of apple buds. *HortScience* 14: 141-142.
- Erez, A., 1987. Chemical control of budbreak. *HortScience* 22: 1240-1243.
- Erez, A., 1995. Means to compensate for insufficient chilling to improve bloom and leafing. *Acta Horticulturae* 395: 81-95.
- Erez, A. 2000. Bud dormancy; phenomenon, problems and solutions in the tropics and subtropic. In: Erez, A. (Ed.), *Temperate fruit crops in warm climate*, pp. 17-48. Bet-Dagan: Kluwer Academic Publishers. 48 pp.
- Erez, A. and Couvillon, G.A., 1987. Characterization of the influence of moderate temperatures on rest completion in peach. *Journal of the American Society for Horticultural Science* 112: 677-680.
- Erez, A., Couvillon, G.A. and Hendershott, C.H., 1979. The effect of cycle length on chilling negation by high temperatures in dormant peach leaf buds. *Journal of the American Society for Horticultural Science* 101: 573-576.
- Erez, A. and Lavee, S., 1971. The effect of climatic conditions on dormancy development of peach buds. I. Temperature. *Journal of the American Society for Horticultural Science* 96: 711-714.
- Erez, A., Lavee, S. and Samish, R.M., 1971. Improved methods for breaking rest in the peach and other deciduous fruit species. *Journal of the American Society for Horticultural Science* 96: 919-522.
- Erez, A., Yablowitz, Z. and Korcinski, R., 2000. Temperature and chemical effects on competing sinks in peach bud break. *Acta Horticulturae* 514: 51-58.
- Erez, A. and Zur, A., 1981. Breaking the rest of apple buds by narrow-distillation-range oil and dinitro-o-cresol. *Scientia Horticulturae* 14: 47-54.
- Esau, K., 1965. *Plant anatomy*. New York: John Wiley.
- Fallahi, E., Simons, B.R., Fellman, J.K. and Colt, W.M., 1992. Use of hydrogen cyanamide for apple and plum thinning. *Plant Growth Regulation* 11: 435-439.

- Fallahi, E., Williams, M.W. and Colt, W.M., 1997. Blossom thinning of 'Law Rome Beauty' apple with hydrogen cyanamide and monocarbamide dihydrogensulfate. *Journal of Tree Fruit Production* 2: 33-44.
- Faust, M., 1989. *Physiology of temperate zone fruit trees*. 338 pp.
- Faust, M., Dehua, L., Wang, S.Y. and Stutte, G.W., 1995a. Involment of apical dominance in winter dormancy of apple buds. *Acta Horticulturae* 395: 47-56.
- Faust, M., Erez, A., Rowland, L.J., Wang, S.Y. and Norman, H.A., 1997. Bud dormancy in perennial fruit trees: physiological basis for dormancy induction, maintenance, and release. *HortScience* 32: 623-629.
- Faust, M., Liu, D., Line, M.J. and Stutte, G.W., 1995b. Conversion of bound to free water in endodormant buds of apple is an incremental process. *Acta Horticulturae* 395: 113-118.
- Faust, M., Millard, M.M. and Stutte, G.W., 1991. Bound versus free water in dormant apple buds-a theory for endodormancy. *HortScience* 26: 887-890.
- Faust, M. and Wang, S.Y., 1993. Biochemical events associated with resumption of growth in temperate zone fruit trees. *Acta Horticulturae* 329: 257-264.
- Ferree, D.C., 1996. Performance of benzyladenine as a chemical thinner on eight apple cultivars. *Journal of Tree Fruit Production* 1: 33-50.
- Fishman, S., Erez, A. and Couvillon, G.A., 1987. The temperature dependence of dormancy breaking in plants: mathematical analysis of Two-Steps model involving a cooperative transtition. *Journal of Theoretical Biology* 124: 473-483.
- Forshey, C.G. and Elfving, D.C., 1989. The relationship between vegetative growth and fruiting in apple trees. *Horticultural Reviews* 11: 229-287.
- Fuchigami, L.H. and Wisniewski, M.E., 1997. Quantifying bud dormancy: physiological approaches. *HortScience* 32: 618-622.
- George, A.P., Broadley, R.H., Nissen, R.J. and Ward, G., 2002. Effects of new rest-breaking chemicals on flowering, shoot production and yield of subtropical tree crops. *Acta Horticulturae* 575: 835-840.
- George, A.P. and Nissen, R.J., 1993. Effect on growth regulants on defoliation , flowering, and fruit maturity of the low chilling peach cultivar Flordaprince in subtropical Australia. *Australian Journal of Experimental Agriculture* 33: 787-795.
- Gilreath, P.R. and Buchnan, D.W., 1981. Rest prediction model for low-chilling 'Sungold' nectarine. *Journal of the American Society for Horticultural Science* 106: 426-429.
- Greene, D.W., 1993. A comparison of the effects of several cytokinins on apple fruit set and fruit quality. *Acta Horticulturae* 329: 144-146.
- Greene, D.W., 1995. Thidiazuron effects on fruit set, fruit quality, and return bloom of apples. *HortScience* 30: 1238-1240.
- Greene, D.W., 2002. Chemicals, timing, and environmetal factors invelved in thinner efficacy on apple. *HortScience* 37: 477-481.

- Greene, D.W., Autio, W.R. and Miller, P., 1990. Thinning activity of benzyladenine on several apple cultivars. *Journal of the American Society for Horticultural Science* 115: 394-400.
- Hauagge, R. and Cummins, J.N., 1991a. Phenotypic variation of length of bud dormancy in apple cultivars and related *Malus* species. *Journal of the American Society for Horticultural Science* 116: 100-106.
- Hauagge, R. and Cummins, J.N., 1991b. Seasonal variation in intensity of bud dormancy in apple cultivars and related *Malus* species. *Journal of the American Society for Horticultural Science* 116: 107-115.
- Honeyborne, G.E. and Rabe, E., 1993. Evaluation of two mineral-oil-based artificial rest-breaking compounds on Golden Delicious apples. *Deciduous Fruit Grower* 43: 206-210.
- Horvath, D.P., Anderson, J.V., Chao, W.S. and Foley, M.E., 2003. Knowing when to grow: signals regulating bud dormancy. *Trends in Plant Science* 8: 534-540.
- Jackson, J.E. 2000. Apple production at low latitudes. In: Erez, A. (Ed.), *Temperate fruit crops in warm climate*, pp. 305-342. Kluwer Academic Publisher. 342 pp.
- Jackson, J.E. 2003. The shoot system. *Biology of apples and pears*, pp. 157-209. Cambridge: 209 pp.
- Jackson, J.E. and Bepete, M., 1995. The effect of hydrogen cyanamide (Dormex) on flowering and cropping of different apple cultivars under tropical conditions of sub-optimal winter chilling. *Scientia Horticulturae* 60: 293-304.
- Jones, K.M., Bound, S.A. and Oakford, M.J., 1992. Identifying the optimum thinning time for red 'Fuji' apples. *Journal of Horticultural Science* 67: -685.
- Jones, K.M., Koen, T.B. and Meredith, R.J., 1983. Thinning 'Golden Delicious' apples using ethephon sprays. *Journal of Horticultural Science* 58: 381-388.
- Jones, K.M., Koen, T.B., Oakford, M.J. and Bound, S.A., 1990. Thinning 'Red Fuji' apples using ethephon at two timings. *Journal of Horticultural Science* 65: 381-384.
- Jones, K.M., Koen, T.B., Wilson, S.J., Oakford, M.J. and Longley, S.B., 1989. A re-examination of the relationship between vegetative growth and flower bud initiation in apples. *Acta Horticulturae* 239: 363-366.
- Krisanapook, K., Ogata, R. and Subhadrabandhu, S., 1990. Study on some cultural practices to induce lateral bud emergence in apple trees grown under warm conditions. *Acta Horticulturae* 279: 275-282.
- Lang, G.A., 1987. Dormancy: a new universal terminology. *HortScience* 22: 817-820.
- Lang, G.A., Early, J.D., Martin, G.C. and Darnell, R.L., 1987. Endo-, para-, and eco-dormancy physiological terminology and classification for dormancy research. *HortScience* 22: 371-377.
- Lavee, S., 1989. Involvement of plant growth regulators and endogenous growth substances in the control of alternate bearing. *Acta Horticulturae* 239: 311-322.
- Lee, R.R., 1994. Interrelationships between flowering habit, fruit characteristics, hydrogen cyanamide applications, and xylem cytokinin levels in 'Rome Beauty' apples (*Malus domestica* Bork.). University of Idaho.

- Link, H., 2000. Significance of flower and fruit thinning on fruit quality. *Plant Growth Regulation* 31: 17-26.
- Linsley-Noakes, G.C., Allan, P. and Matthee, G., 1994. Modification of rest completion prediction models for improved accuracy in south african stone fruits orchards. *Journal of the Southern African Society for Horticultural Sciences* 4: 13-15.
- Linsley-Noakes, G.C., Louw, M. and Allan, P., 1995. Peach production in an area with low winter chilling. *Journal of South African Society of Horticultural Science* 51: 19-24.
- Liu, D., Faust, M., Line, M.J., Millard, M.M. and Stutte, G.W., 1992. State of water in summer dormant apple buds determined by proton magnetic resonance imaging. *Journal of the American Society for Horticultural Science* 118: 632-637.
- Looney, N.E., 1986. Chemical thinning of apples: Some new strategies and important refinements to old precedures. *Acta Horticulturae* 179: 597-604.
- Looney, N.E., 1993. Improving fruit size, appearance, and other effects of fruit crop 'quality' with plant bioregulating chemicals. *Acta Horticulturae* 329: 120-127.
- Luckwill, L.C. 1974. A new look at the process of fruit bud formation in Apple. In: Antoszewski, R., Harrison, L. & Nowosielski, J. (Eds.), *Proceedings of the 19th international horticultural congress* Proceedings of the 19th international horticultural congress, pp. 237-245. Warszawa: 245 pp.
- Naor, A., Flaishman, M., Stern, R., Moshe, A. and Erez, A., 2003. Temperature effects on dormacy completion of vegetative buds in apple. *Journal of the American Society for Horticultural Science* 128: 636-641.
- Nee, C.C. and Fuchigami, L.H., 1992. Overcoming rest at different growth stages with hydrogen cyanamide. *Scientia Horticulturae* 50: 107-113.
- Nir, G., Shulman, Y., Fanberstein, L. and Lavee, S., 1986. Changes in the activity of catalase (EC 1.11.1.6) in relation to the dormancy of grapevine (*Vitis vinifera* L.) Buds. *Plant Physiology* 81: 1140-1142.
- North, M., 1989. Effect of cyanamide and DNOC/oil on budbreak, yield and fruit size of Golden Delicious apples. *South African Journal of Plant and Soil* 6: 176-178.
- Or, E., Vilosny, I., Fennell, A., Eyal, Y. and Ogrodvitch, A., 2002. The transduction of the signal for grape dormancy breaking, induced by hydrogen cyanamide, may involve the SNK-like protein kinase GDBBrPK. *Plant Molecular Biology* 43: 483-489.
- Petri, J.L., Schuck, E. and Leite, G.B., 2001. Effects of thidiazuron (TDZ) on fruiting of temperate tree fruits. *Revista Brasileira de Fruticultura* 23: 513-517.
- Petri, J.L. and Stuker, H., 1995. Effect of mineral oil and hydrogen cyanamide concentrations on apple dormancy, cv. Gala. *Acta Horticulturae* 395: 167.
- Powell, L.E., 1986. The chilling requirement in apple and its role in regulating time of flowering in spring in cold-winter climates. *Acta Horticulturae* 179: 129-139.
- Powell, L.E., 1987. Hormonal aspects of bud and seed dormancy in temperate-zone woody plants. *HortScience* 22: 845-850.

- Richardson, E.A., Seeley, S.D. and Walker, D.R., 1974. A model for estimating the completion of rest for 'Redhaven' and 'Elberta' peach trees. *HortScience* 9: 331-332.
- Rowland, L.J. and Arora, R., 1997. Proteins related to endodormancy (rest) in woody perennials. *Plant Science* 126: 119-144.
- Samish, R.M., 1954. Dormancy in woody plants. *Annual Review of Plant Physiology* 5: 183-204.
- Saure, M.C., 1985. Dormancy release in deciduous fruit trees. *Horticultural Reviews* 7: 239-300.
- Seeley, S.D. and Powell, L.E., 1981. Seasonal changes of free and hydrolyzable abscisic acid in vegetative apple buds. *Journal of the American Society for Horticultural Science* 106: 405-409.
- Shaltout, A.D. and Unrath, C.R., 1983. Rest completion prediction model for 'Starkrimson Delicious' apples. *Journal of the American Society for Horticultural Science* 108: 957-961.
- Steffens, G.L. and Stutte, G.W., 1989. Thidiazuron substitution for chilling requirement in three apple cultivars. *Journal of Plant Growth Regulation* 8: 301-307.
- Tromp, J. 2005. Dormancy. In: Tromp, J., Webster, A. & Wertheim, S.J. (Eds.), *Fundamentals of temperate zone tree fruit production*, pp. 65-73. Leiden: Backhuys Publishers. 73 pp.
- Tromp, J. and Ova, J.C., 1990. Seasonal changes in cytokinin composition of xylem sap of apple. *Journal of Plant Physiology* 136: 606-610.
- Van der Schoot, C. 1996. Dormancy and symplastic networking at the shoot apical meristem. In: Lang, G.A. (Ed.), *Plant dormancy: physiology, biochemistry and molecular biology*, pp. 83-113. Cab International. 113 pp.
- Wang, S.Y. and Faust, M., 1990. Changes of membrane lipids in apple buds during dormancy and budbreak. *Journal of the American Society for Horticultural Science* 115: 803-808.
- Wang, S.Y., Faust, M. and Steffens, G.L., 1985. Metabolic changes in cherry flower buds associated with breaking of dormancy in early and late blooming cultivars. *Physiologia Plantarum* 65: 89-94.
- Wang, S.Y., Ji, Z.L., Sun, T. and Faust, M., 1987. Effect of thidiazuron on abscisic acid content in apple bud relative to dormancy. *Physiologia Plantarum* 71: 105-109.
- Wang, S.Y., Steffens G.L. and Faust, M., 1986. Breaking bud dormancy in apple with a plant bioregulator, thidiazuron. *Phytochemistry* 25: 311-317.
- Weinberger, J.H., 1950. Chilling requirements of peach varieties. *Proceeding of the American Society for Horticultural Science* 56: 122-128.
- Westwood, M.N., Batjer, L.P. and Billingsley, H.D., 1960. Effect of environment and chemical additives on absorption of dinitro-o-cresol by apple leaves. *Proceeding of the American Society for Horticultural Science* 76: 30-40.
- Williams, M.W., 1979. Chemical thinning of apples. *Horticultural Reviews* 1: 270-300.
- Williams, M.W., 1994. Factors influencing chemical thinning and update on new chemical thinning agents. *Compact Fruit Tree* 27: 115-122.

- Williamson, J.G., Krewer, G., Maust, B.E. and Miller, E.P., 2002. Hydrogen cyanamide accelerate vegetative budbreak and shortens fruit development period of blueberry. *HortScience* 37: 539-542.
- Wood, B.W., 1983. Changes in indolacetic acid, abscisic acid, gibberellins, and cytokinins during budbreak in pecan. *Journal of the American Society for Horticultural Science* 108: 333-338.
- Yung, E., Dautlik, T.K. and Belding, R.D., 1995. Respiratory changes during dormancy breaking of apple trees. *Acta Horticulturae* 395: 21-33.
- Zanol, G.C. and Bartolini, S., 2003. Changes in intracellular pH in apricot buds during the winter season. *Advances in Horticultural Science* 17: 97-101.

PAPER 1: Effect of mineral oil and hydrogen cyanamide concentration on dormancy breaking in ‘Golden Delicious’ apple trees

Abstract

South African production areas receive insufficient winter chilling for apple production, necessitating the use of artificial means to break dormancy. Hydrogen cyanamide (HC) alone or in combination with mineral oil (oil) is used as a rest-breaking agent in many deciduous species. The effect of different concentrations of HC and oil on budburst, yield, fruit quality and vegetative growth of mature ‘Golden Delicious’ apple trees were evaluated; the objective was to determine the presence of interaction between the rest-breaking effect of HC and oil when combined at varied concentrations, and to determine appropriate concentrations of HC and oil, to enhance budburst, yield and fruit quality. Three trials were conducted in the Elgin valley (34 °S, 300 m) of the Western Cape, South Africa, in 1999 and 2000. The first trial evaluated four concentrations (0, 0.5, 1 and 2%) of Dormex[®] (hydrogen cyanamide 520 g·L⁻¹) in combination with four concentrations of mineral oil (0, 1, 2, and 4%). The second trial used three concentrations (1, 2 and 4%) of Dormex[®] in combination with three concentrations of mineral oil (1, 2, 4%), plus an unsprayed control, and a treatment of 6% of DNOC (dinitro-o-cresol) Winter Oil[®]. The third trial included five treatments: 0.5% Dormex[®] + 3% oil, 1 % Dormex[®] + 4% oil, 6% DNOC Winter Oil[®], 6% oil and a non-sprayed control. All of the treatments were applied at the first visible signs of budburst. No synergistic effect was observed between oil and HC. Mineral oil at 4% plus 1 to 2% Dormex[®] were sufficient to break dormancy. Dormex[®] at 4% (2.08% HC) reduced fruit set and yield.

Keywords: apples, oil, hydrogen cyanamide, dormancy-breaking.

Introduction

Chilling requirements are a limiting factor for deciduous fruit production in many warm climate regions. Chemical rest-breaking treatments are necessary as a practice to compensate for the lack of chilling. Inadequate winter chilling can modify the budburst pattern and lead to poor budbreak, delayed foliation and protracted bloom, as the major symptoms (Saure, 1985; Erez, 1987).

Oil was the first chemical used to break dormancy. Adding several chemical compounds later enhanced its effect. A combination of dinitro-o-cresol (DNOC) and mineral oil effectively breaks

dormancy of apple buds and has been used extensively since the 1940s (Samish, 1954; Erez and Zur, 1981). However, due to environmental and health considerations, its use was recently discontinued. Other products including calcium cyanamide, thiourea, and KNO_3 , proved to be effective for dormancy release but less efficient than DNOC (Erez *et al.*, 1971; Erez, 1995). The rest-breaking properties of hydrogen cyanamide (HC) were tested in several species since the 1980s, but only later in apples (Shulman *et al.*, 1983). HC alone, and in combination with mineral oil, has shown positive results in apple trees (North, 1992; Petri and Stuker, 1995). HC and oil (1.25+3%), and 5% DNOC oil gave similar budburst and fruit set on four-year-old 'Golden Delicious' trees (North, 1992). Research has determined the optimum combination of oil and HC for dormancy release in apple (1-2,5% Dormex® + 3% oil) (North, 1992; North, 1993). However, the effect on yield and fruit quality in apples has not been quantified; discrepancies have been shown in terms of effects on yield, fruit quality, fruit set and blooming period (North, 1992; North, 1993; Jackson and Bepete, 1995; Petri and Stuker, 1995). One important consideration with the use of HC is its high cost. Reducing the amount of HC in the mixture with mineral oil will reduce the cost of the application, but the extent to which increased oil concentration can substitute for HC is unknown. The interaction between these two rest-breaking treatments is not clear.

The objectives of this study were, firstly, to determine whether an interaction between the rest-breaking effect of HC and oil when combined at varied concentrations is present, and secondly, to determine appropriate concentrations of HC and oil, to enhance budburst, yield and fruit quality of 'Golden Delicious' apple trees, in a region with inadequate winter chilling.

Materials and methods

Three rest-breaking trials were conducted on mature 'Golden Delicious' apples trees, one in the 1999/2000 season and two in 2000/2001, in commercial orchards in Elgin (34 °S, 300 m), Western Cape, South Africa. This area received ca. 610 and 605 Utah model chill units in 1999 and 2000, respectively. The following commercial rest-breaking products were used: Dormex® (hydrogen cyanamide 520 g·L⁻¹), Budbreak® (mineral oil 863.3 g·L⁻¹), and DNOC Winter Oil® (DNOC 3% v/v + mineral oil 72% v/v).

Trial 1

In 1999/2000, four-year-old 'Golden Delicious' apple trees of normal vigour on seedling rootstock at spacing of 4.5 x 1.5 m were treated with different combinations of HC and oil on 6 September

1999. The treatments consisted of four concentrations of Dormex[®] (0, 0.5, 1 and 2% v/v) combined with four concentrations of Budbreak[®] oil (0, 1, 2 and 4 % v/v) resulting in a total of 16 treatments. Treatments were laid out in a randomised complete block design with six replicates, using a 4×4 factorial structure and single tree plots. Treatments were sprayed to run-off using a handgun at the first signs of budburst, evident as “green tip” on a portion of buds on the tree. It should be noted that under conditions of delayed foliation, budburst is slow and protracted and by this stage most buds on the trees, while still closed, did show some swelling. Data collected included the total yield per tree (total mass and number of fruits per tree), and fruit quality, evaluated in a sample of 25 fruit per tree at the time of commercial harvest. Yield efficiency ($\text{kg}\cdot\text{cm}^{-2}$ trunk circumference) and fruit density ($\text{fruit}\cdot\text{cm}^{-2}$ trunk circumference) were calculated from total yield per tree and trunk cross sectional area measured ca. 25 cm above the soil surface. Fruit quality variables measured were: fruit mass, fruit ground colour (as graded on chart, from 1 (green) to 6 (yellow)), stem-end russeting (charts A43 and A40 Capespan, from 1 to 12 (most severe)), retiform russeting (chart A37 Capespan, from 1 to 11(most severe)). From one scaffold branch per tree the following data were recorded: the number of burst and dormant buds on one-year-old shoots and two-year-old branches (after fruit set), flowering intensity (number of inflorescences divided by the total number of buds), fruit set and the fruit set density (total fruit $\cdot\text{cm}^{-2}$ branch cross sectional area measured 10 cm from the insertion point). In order to determine the effect of the treatments on fruit production the following season, the yield (total mass and number of fruit per tree) was recorded at harvest in 2001. All trees were sprayed with 6% DNOC Winter Oil[®] in 2000 (the old “standard” commercial rest-breaking treatment).

Trial 2

Twelve-year-old ‘Golden Delicious’ trees of normal vigour on seedling rootstock planted at 4.5 x 2.0 m, were sprayed with different combinations of HC and oil on 7 September 2000 at the same phenological stage as in Trial 1. The treatments consisted of three concentrations of Dormex[®] (1, 2 and 4% v/v) applied in combination with three concentrations of Budbreak[®] oil (1, 2 and 4% v/v), nine combinations in total. Two additional treatments were included: 6% DNOC Winter Oil[®] as the commercial treatment and a non-sprayed control. All treatments were sprayed to run-off using a handgun. The number of burst buds on one-year-old shoots and two-year-old branches was counted at full bloom and again after fruit set on one scaffold branch per tree; percentage budburst and fruit set were calculated. Total yield per tree (total mass and number of fruits per tree) was determined and fruit quality assessed at harvest time on a sample of 25 fruit per tree as described for Trail 1. After harvest, vegetative growth and spur quality were measured on two 2-year-old branches per tree, randomly sampled from the mid peripheral section of the tree.

The experiment was laid out as a randomised complete block design with 11 treatments, 10 replications, and single tree plots. To determine the interaction between Dormex[®] and oil, the data were analysed as a randomised complete block design with a 3×3 factorial structure. To compare with the two additional treatments, the data were again analysed as complete randomised block design with 11 treatments.

Trial 3

Seventeen-year-old ‘Golden Delicious’ trees of normal vigour on seedling rootstock planted at 4.5 x 2 m, were sprayed on 7 September 2000 (first “green tip”) with the following rest-breaking treatments: 6% DNOC Winter Oil[®]; 6% Budbreak[®] oil; 0.5% Dormex[®] + 3% Budbreak[®] oil; 1 % Dormex[®] + 4% Budbreak[®] oil; and a non-sprayed control. All treatments were sprayed to run-off, using a handgun, and same data as in Trail 2 were recorded. The experiment was laid out as a randomised complete block design with five treatments and ten replicates using single tree plots.

In each trial, the trees were trained to a central leader, were of normal vigour, and had a history of consistent and regular bearing. At all three sites, the orchards received standard commercial cultivation practices, but no thinning treatment was applied.

Data were analysed by analysis of variance using the General Linear Model (GLM) procedure of Statistical Analysis System program (SAS Institute, Cary, NC.). Means were separated by LSD (P = 5%) rank test.

Results

Trial 1

Dormex[®] advanced reproductive budburst and flowering more than oil, reducing considerably the symptoms of delayed foliation. In addition, Dormex[®] condensed the flowering period (time from 10% bloom to 90% petal drop) being more affective at 1% and 2% (Figure 1). No interaction between the HC and oil effects was observed with the evaluated rates. During the season of application (1999/2000), HC influenced budburst, fruit set and yield (Tables 1 and 2). Oil affected only budburst significantly. Budburst increased with Dormex[®] concentration and was ca. 45% more at 1 and 2% rate on one-year-old wood (Table 1). Still significant, oil was less effective than HC but not dependent on rate. Oil did not affect yield (Table 1). Dormex[®] at 1 and particularly 2%

reduced set density, yield efficiency and yield (Tables 1 and 2). The increase in budburst combined with less fruit crop at 1% and 2% Dormex[®] in 1999/2000, resulted in large increases in yield during the next season (2000/2001) (Tables 1 and 2).

Fruit quality was not adversely affected by the rest-breaking treatments (data not shown). In the 1999/2000 season fruit were larger with 1% and 2% Dormex[®], possibly due to a fruit thinning effect. In the 2000/2001 season, it should be mentioned that despite of the increased yield and fruit number the fruit mass was not reduced as expected (Table 2).

Trial 2

As in the previous trial, no interaction was detected between the Dormex[®] and oil concentrations. No significant differences were found between 1% and 2% of Dormex[®] in bud burst, fruit set and yield. Dormex[®] at 4% significantly reduced fruit set and yield. Increasing concentrations of oil did not significantly influence budburst and yield (Tables 3 and 4). Average fruit mass increased with Dormex[®] concentrations. Dormex[®] at 4% resulted in larger fruit, again probably due to a thinning effect (Table 4). Unlike in the previous trial, no negative effect of 2% Dormex[®] on fruit set and yield was observed compared to 1% (Tables 1 and 3). Dormex[®] at 4% enhanced vegetative growth, increasing the number of shoots longer than 10 mm, and together with Dormex[®] 2% possibly increasing the number of leaves per spur (Table 5).

When all combinations, and DNOC-oil, were compared to the unsprayed control, all nine Dormex[®] and oil combinations significantly increased budburst on 2-year-old wood, but not significantly on 1-year-old wood. While not always significantly better than the oil plus 1% or 2% Dormex[®], 6% DNOC-oil gave the highest yield (Tables 3 and 4). Dormex[®] at 4% increased fruit diameter in comparison to the other rates, but fruit shape was not dramatically affected (Table 4).

Trial 3

All rest-breaking treatments increased budburst on 1-year-old wood (Table 6). On 2-year-old-wood only the 1% Dormex[®] plus 4% oil, and the 6% DNOC Winter Oil[®] treatments increased budburst. No treatments effects were observed on fruit set and yield. Vegetative growth on 1-year-old shoots and fruit quality were not affected in this trial (data not shown).

Discussion

Combinations of HC and mineral oil (mixed in the spray tank) can be used to break dormancy and promote more uniform budburst in ‘Golden Delicious’ apple trees when sprayed at the first signs of budburst or “green tip”. No interaction was observed between varied rates of HC and oil. In fact, the rate of oil showed similar response in budburst and yield at concentrations between 1 and 4% (Tables 1 and 3). HC increased budburst with increasing rate. However, in terms of yield, HC appeared to show an optimum rate between 1 and 2% Dormex[®]; in 1999 at 2% and in 2000 at 4% a reduction in yield or a thinning effect was observed. This response was possibly due to flower bud damage by the high rates (2 and 4%). One fact to take into account is that in the 1999/2000 trial the development stage of buds appeared to be more advanced at the time of the spraying compared to the 2000/2001 trials, since more buds have reached green tip at the time of application. This could explain why Dormex[®] at 2% were detrimental in Trail 1 and not in Trial 2. More research is needed on the development stage of buds at the time of application. It is known that later and higher rates of HC can cause phytotoxicity (Erez, 1987; Lee, 1994; Richardson *et al.*, 1994). The problem may reside in the intensity of bud endo-dormancy at the time of application, which influences the efficacy of dormancy breaking and tissue sensitivity to HC (Erez, 1995; Faust *et al.*, 1997). Applications at the bud swelling stage have shown less phytotoxicity (Lee, 1994; Petri and Stuker, 1995). The increased budburst combined with lower fruit set and yield observed with high rates of HC could also result from increased competition from vegetative growth with fruit set. Further trials to determine the dynamics between rest-breaking and the resultant shoot growth, flowering, and fruit set are reported on in Chapters 2 and 3.

An important improvement in budburst was observed with increasing rates of Dormex[®] on spurs and one-year-old shoots that may result in increased spur numbers and possibly improved spur quality (Tables 1, 3 and 5). Petri and Stuker (1995) also observed this effect on ‘Gala’ apples trees after two or three seasons of combined hydrogen cyanamide and oil application. As observed in our data, spur quality was improved (Table 5) and this could result in an increase in the number of flower clusters the following season. However, an increase in flower clusters in the following season may also result from the thinning effect observed at higher rates of Dormex[®] (Tables 1-4). Rest-breaking treatment also normalised and hastened the flowering period (Figure 1) (North, 1989; Lee, 1994; Petri and Stuker, 1995).

Oil appear not to be enough to replace Dormex[®] application, specially for the slight effect on budburst, perhaps it could be an options in cultivars with less chilling requirements.

In conclusion, no synergistic (or antagonistic) effects on budburst and yield were observed when mineral oil and hydrogen cyanamide were combined at different concentrations. The combination of mineral oil and HC is an effective rest-breaking treatment for 'Golden Delicious' apple trees. In this research, mineral oil at 1 to 4% plus Dormex[®] at 1% (0.49% HC) was able to break dormancy without reducing yield or negatively affecting fruit quality. In the second season (Trial 2), yield and fruit set were similar between Dormex[®] 1% and 2%, but budburst was higher at 2%. Probably this rate could be more effective. Dormex[®] at 4% (1.96% HC) reduced fruit set and yield. The improved budburst in response to Dormex[®] application significantly improved the yield in the following season. However, the increase in yield in the following season could also be due to the thinning effect observed at higher rates of Dormex[®]. Further study is needed on the application time and possible effect of Dormex[®] at 1% and 2% on fruit set.

Literature Cited

- Erez, A., 1987. Chemical control of budbreak. *HortScience* 22: 1240-1243.
- Erez, A., 1995. Means to compensate for insufficient chilling to improve bloom and leafing. *Acta Horticulturae* 395: 81-95.
- Erez, A., Lavee, S. and Samish, R.M., 1971. Improved methods for breaking rest in the peach and other deciduous fruit species. *Journal of the American Society for Horticultural Science* 96: 919-522.
- Erez, A. and Zur, A., 1981. Breaking the rest of apple buds by narrow-distillation-range oil and dinitro-o-cresol. *Scientia Horticulturae* 14: 47-54.
- Faust, M., Erez, A., Rowland, L.J., Wang, S.Y. and Norman, H.A., 1997. Bud dormancy in perennial fruit trees: physiological basis for dormancy induction, maintenance, and release. *HortScience* 32: 623-629.
- Jackson, J.E. and Bepete, M., 1995. The effect of hydrogen cyanamide (Dormex) on flowering and cropping of different apple cultivars under tropical conditions of sub-optimal winter chilling. *Scientia Horticulturae* 60: 293-304.
- Lee, R.R.. 1994. Interrelationships between flowering habit, fruit characteristics, hydrogen cyanamide applications, and xylem cytokinin levels in 'Rome Beauty' apples (*Malus domestica* Bork.). University of Idaho.
- North, M., 1989. Effect of cyanamide and DNOC/oil on budbreak, yield and fruit size of Golden Delicious apples. *South African Journal of Plant and Soil* 6: 176-178.
- North, M., 1992. Alternative rest-breaking agent for apples. *South African Journal of Plant and Soil* 9: 39-40.

- North, M., 1993. Effect of application date on the rest-breaking action of cyanamide on 'Golden Delicious' apples. *Deciduous Fruit Grower* 43: 470-472.
- Petri, J.L. and Stuker, H., 1995. Effect of mineral oil and hydrogen cyanamide concentrations on apple dormancy, cv. Gala. *Acta Horticulturae* 395: 167.
- Richardson, A.C., Dawson, T.E., Hampton, R.E. & Blank, R.H. The effects of hydrogen cyanamide and mineral oil on kiwifruit performance. 47, 314-319. 1994.
- Samish, R.M., 1954. Dormancy in woody plants. *Annual Review of Plant Physiology* 5: 183-204.
- Saure, M.C., 1985. Dormancy release in deciduous fruit trees. *Horticultural Reviews* 7: 239-300.
- Shulman, Y., Nir, G., Fanberstein, L. and Lavee, S., 1983. The effect of cyanamide in the release from dormancy of grapevine buds. *Scientia Horticulturae* 19: 97-104.

Table 1. Effect of Dormex[®] and mineral oil application in 1999 on budburst, fruit set and yield of 'Golden Delicious' apple trees in Elgin, South Africa.

Treatment	Budburst		Flower Density (%) ^W	Set density (No of fruit cm ⁻² BCSA ^X)	Yield efficiency (kg cm ⁻² TC SA ^Y)		Fruit density (Number of fruit cm ⁻² TC SA ^Y)	
	(%)				2000	2001	2000	2001
	Spurs	1-year-old wood						
Dormex (%)								
0	49.3 c ^Z	57.8 c	17.9	1.35 ba	0.149 a	0.155 b	1.30 a	1.22 b
0.5	59.3 c	67.1 b	17.3	1.67 a	0.180 a	0.163 b	1.55 a	1.33 b
1	75.9 b	82.8 a	14.1	1.04 b	0.104 b	0.232 a	0.81 b	1.95 a
2	86.2 a	84.8 a	16.7	0.43 c	0.060 c	0.233 a	0.43 c	1.90 a
Oil (%)								
0	60.7 c	66.9 b	16.7	1.07	0.130	0.176	1.11	1.44
1	73.4 ba	73.4 ba	20.9	1.13	0.128	0.208	1.04	1.72
2	63.6 bc	76.6 a	14.5	1.19	0.125	0.203	1.04	1.65
4	73.1 a	75.7 a	14.1	1.09	0.108	0.195	0.90	1.59
Pr > F								
Dormex (D)	<.0001	<.0001	0.8878	0.0005	<.0001	0.0090	<.0001	0.0116
Oil (O)	0.0169	0.0312	0.5308	0.9784	0.6724	0.7273	0.5900	0.7469
D x O	0.6312	0.3463	0.4365	0.1051	0.5874	0.3394	0.5977	0.4881

^W Percentage of reproductive buds burst from one scaffold branch per tree.

^X Branch cross sectional area.

^Y Trunk cross sectional area.

^Z Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 2. Effect of Dormex[®] and mineral oil application in 1999 on yield and fruit mass 'Golden Delicious' apple trees in Elgin, South Africa.

Treatment	Yield (t ha ⁻¹)			Number of fruit tree ⁻¹		Mean fruit mass (g)	
	2000	2001	2000+2001	2000	2001	2000	2001
Dormex (%)							
0	23.1 ba ^Z	24.0 b	47.1	137 a	128 c	115.7 b	131.7
0.5	28.8 a	27.2 b	56.0	170 a	151 b	116.9 b	127.1
1	17.7 b	39.4 a	57.1	94 b	224 a	129.5 a	125.2
2	9.9 c	39.0 a	48.9	49 c	218 a	133.3 a	126.1
Oil (%)							
0	22.3	29.6	51.9	127	163	122.6	124.6
1	21.5	36.2	57.8	119	204	124.3	128.7
2	18.8	31.0	49.9	107	171	123.5	127.3
4	16.7	32.7	49.5	93	183	124.8	129.5
Pr > F							
Dormex (D)	<.0001	0.0106	0.4803	<.0001	0.0123	0.0006	0.4769
Oil (O)	0.2980	0.6752	0.6908	0.2417	0.6531	0.9744	0.7065
D x O	0.5244	0.5110	0.4483	0.3556	0.6610	0.8516	0.3211

^Z Means followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 3. Effect of Dormex[®] and mineral oil application in 2000 on budburst, fruit set and yield of 'Golden Delicious' apple trees in Elgin, South Africa.

Treatment	Budburst (%)		Fruit set (%)	Production efficiency (kg cm ⁻² TCSA ^Y)	Fruit density (Number of fruit cm ⁻² TCSA ^Y)
	2-year-old wood	1-year-old wood			
Dormex (%)					
1	96 ab ^Z	93 b	11.5 a	0.288 a	2.48 a
2	98 a	95 ab	11.6 a	0.326 a	2.65 a
4	95 b	97 a	8.7 b	0.131 b	0.97 b
Oil (%)					
1	96	94	11.6	0.245	2.02
2	96	94	9.2	0.244	1.98
4	97	95	11.0	0.255	2.09
Pr > F					
Dormex (D)	0.0052	0.0445	0.0266	0.0001	<.0001
Oil (O)	0.3515	0.4181	0.1155	0.9084	0.9806
D x O	0.4373	0.5979	0.4133	0.6461	0.8122
Dormex(%) + Oil(%)					
1 + 1	93.6 ab	93.0	13.7	0.282 a	2.43 a
2 + 1	97.2 ab	96.5	10.9	0.303 a	2.53 a
4 + 1	96.0 ab	96.2	10.5	0.157 b	1.17 b
1 + 2	97.3 ab	93.7	8.7	0.283 a	2.40 a
2 + 2	98.4 ab	92.0	12.0	0.322 a	2.59 a
4 + 2	92.6 b	95.0	7.1	0.137 b	1.06 b
1 + 4	96.6 ab	92.4	12.3	0.297 a	2.58 a
2 + 4	99.0 a	96.0	12.0	0.355 a	2.84 a
4 + 4	95.1 ab	98.3	8.4	0.089 b	0.63 b
Unsprayed control	75.0 c	81.7	11.5	0.282 a	2.57 a
6% DNOC-oil	90.5 b	88.8	9.4	0.362 a	2.91 a
Pr > F	0.0002	0.2122	0.1362	<.0001	<.0001

^YTrunk cross sectional area.

^ZMeans followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 4. Effect of Dormex® and mineral oil application in 2000 on yield and fruit size of ‘Golden Delicious’ apple trees in Elgin, South Africa.

Treatment	Yield (t ha ⁻¹)	Number of fruit tree ⁻¹	Mean fruit mass (g)	Mean fruit diameter (mm)	Fruit length: diameter ratio
Dormex (%)					
1	45.5 a ^Z	350 a	118.9 c	64.9 b	0.963 a
2	47.1 a	341 a	127.0 b	65.7 b	0.939 b
4	22.1 b	149 b	139.4 a	68.1 a	0.943 ab
Oil (%)					
1	38.4	282	127.3	66.0	0.948
2	37.5	272	130.3	66.4	0.951
4	38.6	284	128.1	66.3	0.945
Pr>F					
Dormex (D)	<.0001	<.0001	<.0001	<.0001	0.0427
Oil (O)	0.9783	0.9503	0.5681	0.4711	0.7229
D x O	0.4450	0.5952	0.9647	0.2084	0.4342
Dormex(%) + Oil(%)					
1 + 1	44.9 a	348 a	118.2 cd	64.3 c	0.956 ab
2 + 1	43.4 a	322 a	125.9 bcd	66.3 bc	0.939 b
4 + 1	28.2 b	189 b	135.9 ab	67.2 ab	0.951 ab
1 + 2	45.9 a	348 a	120.7 cd	64.9 bc	0.984 a
2 + 2	46.5 a	329 a	128.9 bc	65.6 bc	0.934 b
4 + 2	21.9 b	152 b	140.2 ab	68.5 a	0.936 b
1 + 4	45.6 a	354 a	117.8 cd	65.4 bc	0.951 ab
2 + 4	51.9 a	376 a	126.3 bcd	65.2 bc	0.943 ab
4 + 4	14.8 b	94 b	142.9 a	68.6 a	0.941 ab
Unsprayed control	45.5 a	370 a	113.7 d	66.3 bc	0.931 b
6% DNOC Winter Oil	58.6 a	431 a	128.3 bcd	64.7 c	0.953 ab
Pr > F					
	<.0001	<.0001	0.0003	<.0001	<.0001

^ZMeans followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 5. Effect of Dormex[®] and mineral oil application in 2000 on vegetative growth and spur quality of 'Golden Delicious' apple trees in Elgin, South Africa.

Treatment	Terminal shoot length (mm)	Shoot distribution according to length (%)			Mean length of shoots >10mm long (mm)	Number of leaves on spurs ≤5mm
		≤5 mm	5-10 mm	>10 mm		
Dormex (%)						
1	255.9	68.6 a ^Z	15.2	16.2 b	44.0 b	2.9 b
2	251.8	69.3 a	11.8	19.8 b	57.2 b	3.4 a
4	234.3	44.3 b	11.5	44.1 a	83.6 a	3.4 a
Oil (%)						
1	246.5	59.2	16.2	24.6	62.8	3.1
2	258.5	65.2	10.9	31.3	68.4	3.4
4	234.9	65.2	11.4	23.3	53.7	3.1
Pr > F						
Dormex (D)	0.6441	0.0001	0.1572	0.0001	0.0019	0.0171
Oil (O)	0.5613	0.3336	0.2109	0.1103	0.5594	0.2852
D x O	0.3416	0.5307	0.4767	0.6154	0.2942	0.1872
Dormex(%) + Oil(%)						
1 + 1	259.2	65.7 ab	20.6	13.7 b	33.6 cd	3.1 ab
2 + 1	273.8	71.9 ab	14.2	13.9 b	49.6 cd	3.2 ab
4 + 1	206.2	40.1 c	14.9	45.0 a	100.3 a	3.0 ab
1 + 2	246.6	71.6 ab	8.9	19.5 b	55.2 bcd	3.0 ab
2 + 2	252.1	60.6 abc	11.9	27.5 ab	57.1 bcd	3.4 a
4 + 2	274.9	42.7 c	11.9	45.4 a	90.3 ab	3.7 a
1 + 4	259.3	68.0 ab	17.0	15.0 b	41.1 cd	2.5 b
2 + 4	224.0	76.0 a	8.5	15.5 b	66.7 abc	3.5 a
4 + 4	215.2	51.0 bc	7.4	41.6 a	56.5 bcd	3.5 a
Unsprayed control	225.7	65.4 ab	17.2	17.4 b	19.9 d	3.0 ab
6% DNOC Winter Oil	252.2	65.2 ab	13.0	21.8 b	35.8 cd	2.9 ab
Pr > F						
	0.7209	0.0009	0.5469	<.0001	0.0030	0.0375

^ZMeans followed by the same letter within the same column do not differ significantly at P = 0.05.

Table 6. Effect of rest-breaking treatment application in 2000 on bud-break, fruit set and yield of 'Golden Delicious' apple trees in Elgin, South Africa.

Treatment	Bud-break (%)		Fruit set (%)	Production efficiency (kg cm ⁻² TCSA ^Y)	Fruit density (Number of fruit cm ⁻² TCSA ^Y)	Number of fruit per tree
	2-year-old wood	1-year-old wood				
Unsprayed control	50.3 c	51.1 b	14.8	0.239	2.39	364.7
6% Oil	58.3 bc ^Z	69.0 a	16.1	0.250	2.44	361.0
0.5% Dormex + 3%Oil	72.0 abc	82.1 a	14.8	0.241	2.46	408.0
1% Dormex + 4%Oil	77.2 ab	85.4 a	13.2	0.273	2.69	372.8
6% DNOC Winter Oil	89.4 a	85.9 a	14.0	0.295	2.95	421.7
Pr > F	0.0099	0.0007	0.9058	0.7470	0.8797	0.9270

^YTrunk cross sectional area.

^ZMeans followed by the same letter within the same column do not differ significantly at P = 0.05.

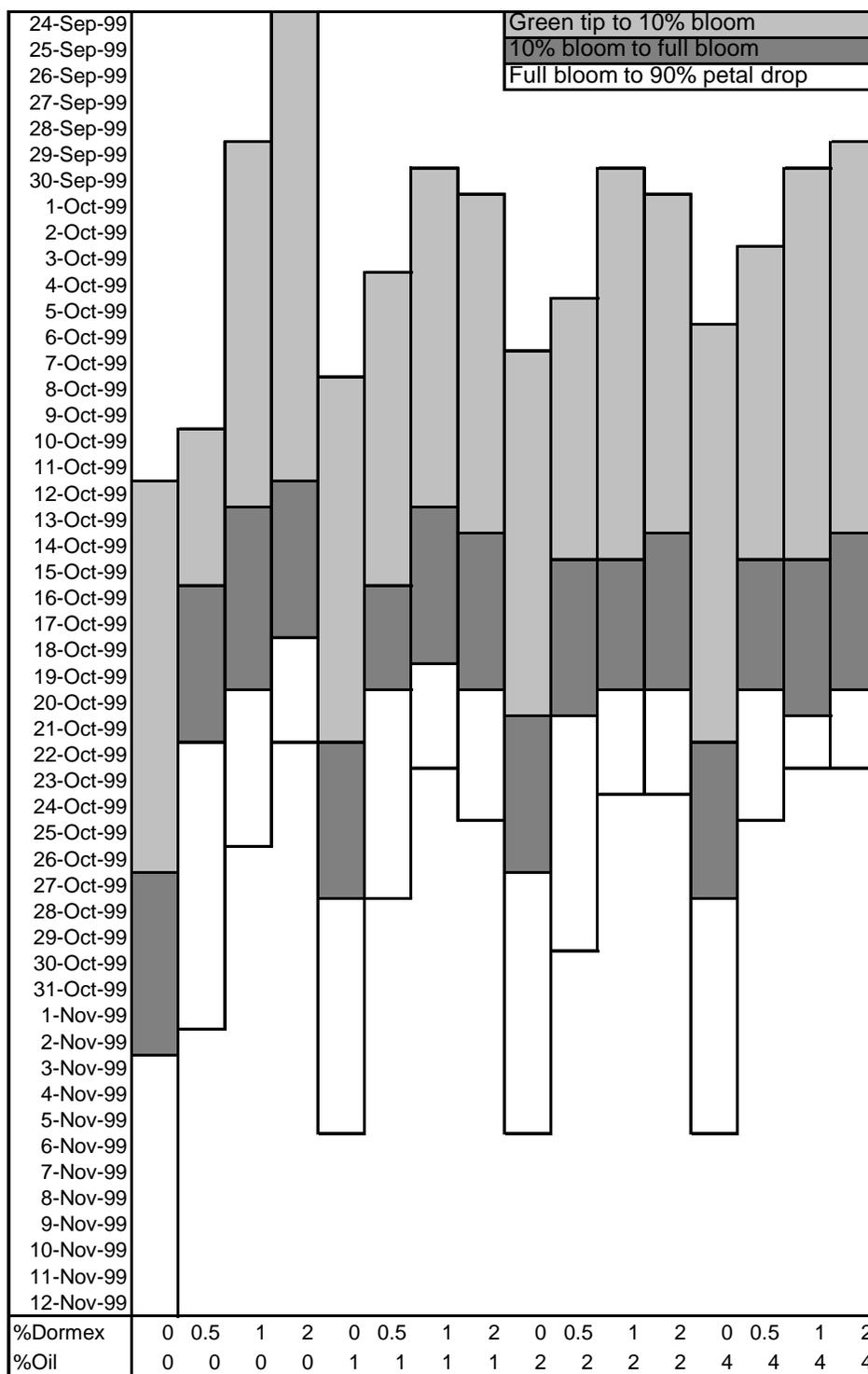


Figure 1. Effects of Dormex® and mineral oil application in 1999 on the development of flowering on single branches of 'Golden Delicious' apple trees in Elgin, South Africa.

PAPER 2: Bud burst and flowering patterns of apple trees as modified by chemical rest-breaking treatments

Summary

In warm areas apples require rest-breaking treatments to compensate for the lack of winter chilling. These treatments influence the bud break response of vegetative and reproductive buds. The objective of this study was to determine the effect of hydrogen cyanamide (HC) in combination with oil, thidiazuron (TDZ) formulated with oil and dinitro-*o*-cresol (DNOC) also formulated with oil, on the bud burst and flowering patterns of apple trees grown under marginal winter chilling conditions. The research was carried out in the Elgin area (34°S, 300 m), South Africa, over a period of three years. In 2001, the effect of HC was compared to that of a mixture of DNOC and oil. The treatments that were used were the following: a mixture of HC as Dormex[®] (49% v/v HC) at two rates (0.245% and 0.49% v/v for 'Royal Gala'; 0.49% and 0.98% for 'Golden Delicious') in combination with oil at 4%; and 6% DNOC/oil (DNOC 3% + mineral oil 72% v/v). There was one unsprayed control. In the 2002 and 2003 trials, the following mixtures were used: HC and oil, and TDZ and oil. The treatments that were used were the following: a mixture of HC (in the same two concentrations as used in the previous year) and 4% oil, for both cultivars, and a mixture of TDZ-oil, as Lift[®] (TDZ 3 g·L⁻¹, oil + co-adjuvants) at two concentrations, namely 3% and 5% for 'Royal Gala' in 2002 and 2003' and 4% and 6% for 'Golden Delicious'. There was one unsprayed control for each cultivar. Vegetative and reproductive development were assessed on two branches per tree, from lower and upper canopy positions. In general, the rest breaking treatments enhanced the final vegetative bud burst compared to the control, while reproductive bud burst in 2002 and 2003 was not significantly influenced. The treatments compressed and advanced flowering periods, but this effect was not always evident when the spring was warm. The treatments synchronised flowering on the tree and between the two cultivars. The mixture of 0.245% HC and 4% oil was less effective in terms of increasing bud burst in 'Royal Gala' compared to other rest-breaking treatments. The mixture of 0.49% HC and 4% oil effectively compressed and synchronised flowering in 'Golden Delicious'. TDZ-oil used at the lower rates also increased bud burst and concentrated flowering. However, it appears that after a cooler winter, higher rates could result in an exacerbated bud burst effect with excessive vegetative growth. The implications for chemical thinning treatments must still be considered.

Key words: apples, bud burst, flowering pattern, hydrogen cyanamide, thidiazuron

Introduction

When apples and other temperate-zone fruit trees are grown in warm climates there is often inadequate winter chilling to break dormancy and then delayed foliation occurs (Saure, 1985). The symptoms include delayed, reduced and protracted foliage development and bloom (Saure, 1985; Erez, 1987; Erez, 2000). Terminal buds will often burst long before lateral buds (Cook and Jacobs, 1999). With extended flowering periods, the determination of full bloom dates is difficult. This can further complicate the application of chemical thinning agents.

Not all buds on a tree require similar winter chilling, and buds react individually (but not independently) in terms of the chilling response. Flower buds have a lower chilling requirement than vegetative buds, and terminal buds have a lower chilling requirement than lateral buds (Samish and Lavee, 1962, cit. Saure, 1985). Among lateral buds there may be noticeable differences relative to position on the shoot. Chandler (1960) found that in apple the dormancy influence was weakest in the latent buds of older wood. In long shoots, the author observed that the dormancy was stronger in the basal part than in the apical part in late summer and autumn, but in spring after a winter with adequate chilling, it was weaker in the basal part. This has been explained as a gradient of bud burst where basitony is predominant at the beginning of dormancy, and toward the end of dormancy there is a return to acrotony (Crabbé, 1984; Cook *et al.*, 1998). Extended chilling, however, does tend to normalise these differences (Cook *et al.*, 1998). No artificial treatments can fully replace the chilling required to normalise bud burst, and partial chilling is required before artificial rest-breaking treatments become effective (Erez, 2000).

Many chemicals have been tested for their dormancy-breaking activity, such as dinitro compounds, oils, cyanamides, potassium nitrates, thioureas and growth regulators (Samish, 1954; Erez, 1979; Saure, 1985; Erez, 2000). Only a few rest-breaking treatments are used commercially. The active chemicals have no common characteristic, besides the fact that many of them are only effective at sub-lethal doses (Erez, 1987; Erez, 2000). Some of the rest-breaking chemicals, such as hydrogen cyanamide, inhibit catalase and, as a result, allow activation of certain peroxides (Erez, 1987; Pérez and Lira, 2005). Other chemicals such as TDZ that interfere with aerobic respiration have been found to have a strong effect on dormant buds (Faust *et al.*, 1991). The activity of the chemicals sprayed to break dormancy induces increases in gibberellins and cytokinins which are promoters of budburst (Erez, 1987).

The application times and rates of rest-breaking treatments have been determined primarily on the bud burst response, but also in terms of fruit set and yield response. Although the efficacy of hydrogen cyanamide (HC) on apple tree dormancy release has been widely confirmed, there have been discrepancies in terms of the effect on yield, fruit quality, fruit set and the bloom period (Erez, 2000). Under insufficient winter chilling conditions, in several apple cultivars, blossom synchronization has been reported when 1.5% HC (3% Dormex) was used (Jackson and Bepete, 1995). However, at the same rates, HC significantly reduced the fruit set of ‘Dorsett Golden’ compared to an untreated control (El-Kassas *et al.*, 1996). 2% Dormex (HC 49%) reduced fruit set density and yield of ‘Golden Delicious’ in one year but increased yield in the following year in the same trees, regardless of the oil concentration (from 0 to 4%) (Paper 1). On the other hand, North (1989) found that 2.5% HC significantly increased fruit set in ‘Golden Delicious’ apples relative to the control. The main reason for the variable results may relate to the level of endo-dormancy of the buds. Resistance to the phytotoxic effect of HC declines rapidly following dormancy release (Erez, 2000). TDZ was found to be more effective than natural cytokinins in breaking dormancy in apple buds (Wang *et al.*, 1986a). TDZ also reduced the number of chilling units required to achieve bud break (Faust *et al.*, 1991).

It is widely accepted that chemical rest-breaking treatments modify bud burst and flowering patterns. The flowering period is usually compressed and advanced, which can interact with other cultural practices such as chemical thinning programmes. To the authors’ knowledge there are no specific data available on the effects of rest-breaking treatments on the flowering pattern of apple trees, especially under conditions of marginal winter chilling. The objective of this study was therefore to determine the effect of HC and TDZ in combination with oil on the bud burst and flowering patterns of apple trees grown under marginal winter chilling conditions.

Materials and methods

Plant material and orchard conditions

This research was conducted on ‘Royal Gala’ and ‘Golden Delicious’ apple trees over three seasons, from 2001 to 2003, in the Elgin region (34 °S, 300 m), Western Cape, South Africa. According to Hauagge and Cummins (1991), ‘Gala’ apple trees require 1000 Utah model chill units (CU) (Richardson *et al.*, 1974), while according to Erez (2000) ‘Golden Delicious’ apple trees require 1200 CU.

In 2001, Elgin received 820 CU from May through to August. The trials were conducted in commercial orchards on uniform 5-year-old apple trees on M793 rootstock. The 'Golden Delicious' trees were planted at a spacing of 4.5 m x 1.5 m, and 'Royal Gala' at 4.5 m x 2 m. 'Hillieri' crab apples (*Malus hupehensis* (Pamp.) Rehder) were planted at 11% of the plant density for cross-pollination. In 2002 Elgin received 872 Utah CU. Eight-year-old 'Golden Delicious' apple trees on M793 rootstock planted at 4 m x 1.25 m spacing, and nine-year-old 'Royal Gala' apple trees planted at 4 m x 1.5 m spacing were used. Both orchards were on M793 rootstock with 11% 'Granny Smith' for cross-pollination. In 2003 only 754 CU were accumulated. One 5-year-old commercial orchard planted at 1.5 m x 4.5 m on M793 rootstock was used, with 'Golden Delicious' and 'Royal Gala' apple trees alternated every two rows. In each trial, the trees were trained to a central leader, were of normal vigour, and had a history of consistent and regular bearing. At all the sites, the orchards received standard commercial cultivation practices.

Experiments

The experimental layout in all trials was a randomised complete block design. The 2001 trials consisted of four treatments, six replications, and single tree plots. The treatments were: HC (Dormex[®] 520 HC g·L⁻¹) at two rates (0.245% and 0.49% v/v for 'Royal Gala'; 0.49% and 0.98% v/v for 'Golden Delicious'), in combination with 4% oil (Budbreak[®], mineral oil 863.3 g·L⁻¹); 6% DNOC/oil (Winter Oil[®], DNOC 3% v/v + mineral oil 72% v/v); and an unsprayed control. The 2002 trials were designed with five treatments, ten replications for 'Golden Delicious' and eight replications for 'Royal Gala', and single tree plots. The treatments were: HC (at the same two concentrations used in the previous year), in combination with 4% oil, for both cultivars; TDZ-oil (Lift[®], TDZ 3 g·L⁻¹, oil + adjuvants) at two concentrations (3% and 5% for 'Royal Gala' and 4% and 6% for 'Golden Delicious'), and one unsprayed control for each cultivar. In 2003, the same treatments were used as in 2002, but with only six replications per cultivar and one tree per plot.

The 'Golden Delicious' trees were sprayed to run-off, using a handgun, on 26 Sept. 2001 (955 CU), 7 Sept. 2002 (906 CU) and 15 Sept. 2003 (832 CU). The 'Gala' trees were sprayed on 20 Sept. 2001 (938 CU), 2 Sept. 2002 (875 CU) and 15 Sept. 2003 (832 CU). Since some phytotoxicity, symptoms were observed on 'Golden Delicious' in 2001, the spraying in 2002 was performed once 75% of the chilling requirement was satisfied. In 2003, the treatments were applied earlier due to the occurrence of some flower and fruit deformations with the TDZ treatments on 'Golden Delicious'. Besides the differences in chilling, the spring temperatures were warm, with 5970, 6950, 6330 growing degree hours (GDH) (Richardson *et al.*, 1975) accumulating in Sept. 2001,

2002 and 2003, respectively. By the spray date, 5027, 1413, 2961 GDH had accumulated for 'Golden Delicious', and 3718, 441, 2961 GDH for 'Gala' in the years 2001 through 2003, respectively.

Evaluations

Vegetative and reproductive development was assessed on two randomly selected branches per tree, with similar orientation and vigour, from lower and upper canopy positions. The branches varied in length from ca. 80 to 120 cm and included both spurs on older wood and year-old shoots.

Twelve reproductive development stages were considered: dormant buds, bud swelling, green tip, mouse ear, early green cluster, late green cluster, pink cluster, pink balloon, first flower, full bloom, petal fall, fruit set and fruit growth, according to Fleckinger growth stages. Vegetative bud burst was scored when the first expanding green leaves were visible.

In 2001, flower and vegetative buds were counted separately on year-old wood or on spurs on 2-year or older wood. Buds at different phenological stages were counted weekly. In 2002, the total number of flower buds at different phenological stages per branch was counted every 3-5 days, but no distinction was made according to wood age. In 2003, the total number of open flowers was counted every 3-5 days. A flower was considered open when it appeared that a bee could enter and pollinate it. Flowers were not counted when they had lost more than two petals. Vegetative bud burst was assessed less frequently, and only on the lower branch in 2002 and 2003. Branch circumference (BC) was measured 10 cm from the insertion point.

Accumulated flowering over time for individual plants revealed a simple sigmoid pattern. A logistic curve ($Y = K / (1 + e^{-\alpha t - \beta})$) was fitted for each tree, where K is the maximum value reached (the total number of flowers or flowering clusters), α is the rate (rate of flowering) and β is the location parameter and equal to $-T_m \cdot \alpha$. T_m measures the time of $K/2$, which is the inflection point (where 50% of flowering had occurred or when the maximum rate of flowering took place). Parameters obtained from the fitted curves were used to estimate the following variables for each plant: the time from 10 to 90% bloom; and the time to 10, 50, 75, and 90% bloom. Vegetative and reproductive bud burst was expressed as the number of growing units per centimetre of branch circumference. Values were analysed statistically by analysis of variance using the General Linear Model (GLM) procedure of Statistical Analysis System program (SAS Institute, Cary, NC.), and means were separated by LSD ($P=5\%$) rank test.

Results

'Golden Delicious'

The effect of the rest-breaking (RB) treatments on bud burst was different for the three years of study. In 2001, the three RB treatments enhanced the final budburst on old wood (>one-year-old), but no differences were detected on the proportion of vegetative and reproductive buds (Table 1). In 2002, final vegetative bud burst was improved only by the TDZ-oil treatments and, in 2003 by all the RB treatments, whereas reproductive bud burst evaluated in 2002 and 2003 was not significantly influenced by any of the RB treatments (Table 1).

Vegetative bud burst evolved differently over the three years of study (Figure 1). In 2001, the evolution was similar for all the treatments, but less intense in the untreated control (Figure 1). In 2002, the TDZ-oil treatments resulted in higher vegetative bud burst compared to the HC-oil treatments evident. This was observed from about 4 weeks after the application (Figure 1). In 2003, all the rest-breaking treatments showed a similar progression of vegetative bud burst (Table 1), but the control showed less intense bud break during the observed period (Figure 1).

In 2001, flowering was protracted in the control treatment where the period from 10 to 90% bloom was about 20 days (Table 2, Figure 2). Bloom with all the RB treatments was generally shorter and the flowering gradient was steeper. However, in 1-year-old wood only HC 0.49% + oil 4% shortened bloom significantly (Table 2, Figure 2). Flowering was delayed in the control and 0.98% HC + 4% oil treatments, where 50% bloom was reached later (Table 2). Fifty % bloom with 6% DNOC/oil and 0.49% HC + 4% oil occurred at about 6300 GDH accumulated from treatments application. 0.98% HC + 4% oil treatment and the control required about 1000 GDH more (Table 2).

In 2002 and 2003, the measurements of the blooming period were analysed according to branch position. In these years, the effects of the rest-breaking treatments were less clearly defined than in 2001 (Tables 3 and 4). In 2002, RB treatments had different effects depending on branch position. On the upper branch the rest-breaking treatments did not significantly affect the flowering period compared to the control. However, HC 0.49% + oil 4% significantly reduced the blossom duration compared to the other HC treatment and to TDZ-oil 6%. HC 0.49 + oil 4% had the steeper flowering gradient, being equal only to TDZ-oil 6%. There was no effect on the days after spraying (DAS) to 50% bloom (Table 3, Figure 3). On the lower branch, 0.98% HC + 4% oil advanced the date of 50% bloom by two days compared to other treatments (Table 3 and Figure 3). In 2003, the

rest-breaking treatments did not significantly reduce the bloom period compared to the control, although there was a tendency for the TDZ-oil treatments to result in flowering over a shorter period (Table 4 and Figure 4). The trees treated with a mixture of HC and oil did flower slightly earlier, by a few days. In the upper branch the two TDZ-oil treatments reduced the flowering period and increased the blossom gradient compared to the HC-oil (Table 4).

'Royal Gala'

All RB agents increased the final bud burst in 2001. RG agents also increased vegetative bud burst in 2002 in 'Royal Gala' (Table 5), with the exception of 0.245% HC + 4% oil in 2002 (Table 5).

The evolution of vegetative bud burst was very different in the three years of study. In 2001, vegetative bud burst evolved similarly for all the treatments up to 4 weeks after the application, after which it was increased by the rest-breaking treatments (Figure 5). In 2002, treatments evolved similarly but no differences were observed between 0.245% HC + 4% oil, and the control, 4 week after treatment application (Figure 5). In 2003, the effect of the rest-breaking treatments were only slightly more intense than in the case of the control with the TDZ-oil treatment at 5% stimulating more vegetative bud break (Figure 5).

In 2001, the bloom period on older wood and in total was shortened by 7-11 days by the rest-breaking treatments (Table 6). On one-year-old shoots, no significant effects were observed, although the flowering period trends were similar to older wood. Fifty % bloom was significantly earlier following rest-breaking treatments on older wood and in total, but not on the one-year-old wood (Table 6). The flowering gradient in response to the RB treatments was also steeper on older wood and in total, but not on the one-year-old wood (Table 6 and Figure 6).

In 2002, the bloom period was not significantly affected by the RB treatments on the upper branch (Table 7 and Figure 7). On the lower branch 0.245% HC + 4% oil and 5% TDZ-oil treatments reduced the flowering period. No effects on number of DAS to 50% bloom were observed, but the flowering gradient was steeper with some treatments (Table 7). On the upper branch 5% TDZ-oil and both HC and oil combinations increased the flowering gradient (Table 7). On the lower branch only 0.245% HC + 4% oil increased the flowering gradient (Table 7).

In 2003, the HC and oil combinations shortened the blooming period on the upper branch compared to the control, but not compared to TDZ-oil treatments in the upper branch (Table 8). No differences were observed on the flowering gradient. However, 50% bloom was attained earlier

with the HC and oil combinations and TDZ-oil 5% compared to the control (Table 8). On the lower branch all rest-breaking treatments significantly shortened the bloom period and had a steeper flowering gradient (Table 8 and Figure 8). The number of DAS to 50% bloom did not differ in the lower branch compared to the control (Table 8).

Discussion

The rest-breaking treatments generally increased bud burst. The RB treatments did not always compressed and advance blossom. The effect was mostly dependent on the application rate.

The intensity of reproductive bud burst was not influenced. This can be expected considering that reproductive buds are determined from the previous season and they have lower chilling requirements than vegetative buds where dormancy depth is more variable (Saure, 1985). Therefore, in a relative warm climate, an increased in total bud burst would mainly be reflected in an increase in vegetative bud burst. Increasing vegetative bud burst is of great importance fact for the tree productivity since through increasing the potential number of bearing positions, the reproductive potential for the following season should be increased.

Rest breaking treatments enhanced and advanced vegetative bud burst, and could thereby improve spurs quality and floral induction for the following season. Time of differentiation is decisive for a reproductive bud and flower quality. Luckwill (1974) claimed that when the flower induction occurs late in the season, the flower buds are physiological relatively young and, as a consequence, in spring the axis of the inflorescence become elongated, the spurs leaves are larger, the flowers are fewer within the inflorescence and the peduncles are longer than usual and thereby, resulting in poor fruit set. Other authors stated that the more developed the flower primordia are within the bud in autumn, the better the chance of flowers to be fertilised at bloom time in spring (Stockert and Stösser, 1996). Flower differentiation may only commence after some primordia of vegetative organs have been initiated on the bud axis (Bubán and Faust, 1982). Therefore, an earlier vegetative budburst will allow a better bud development which would increase the ability of buds to be inducted early in the season. On the other hand, excessive vegetative bud break may negatively affect fruit set, because of sink competition, as found by Erez (2000) in peach. Since earlier developing organs inhibit later ones by 'primigenic dominance' (Bangerth, 1989), the synchronisation of reproductive and the enhanced vegetative bud burst may decrease fruit set. In flower and fruitlet abscission, competition phenomena are involved within and between flower and

fruit clusters, and between clusters and developing shoots (Bangerth, 1986; Gruber and Bangerth, 1990). However, it has to be considered that increased vegetative growth for an increased crop load in response to the stimulation of bud burst by RB agents may also be leading to a higher availability of assimilates, resulting in increased final fruit size.

Symptoms of lack of chilling on plant development were observed for both cultivars, but were generally more noticeably in 'Golden Delicious'. The major effect observed on the control treatment on both varieties was a reduced bud burst. The symptoms described as delayed foliation and protracted flowering period (Samish, 1954; Saure, 1985; Erez, 1987; Erez, 2000) were also evident. In 2001, the RB treatments synchronized the occurrence of 50% bloom between wood of different ages, 1-year-old wood and older. Normally terminal buds on one-year-old shoots burst earlier since they have lower chilling requirements, this has been observed either in warm climates (Samish, 1954; Erez, 2000) and in fully chilled trees (Lee, 1994). Lee (1994) found that HC applied at 2.5% synchronized 1-year-old and 2-year-old wood bud break in 'Romy Bauty' apple.

The upper branch generally flowered later than the lower. Rest-breaking treatments resulted in advanced bloom in the upper branch in 'Royal Gala' in 2002 and 2003 (Tables 7 and 8) and, as a result, synchronisation in bud development between the upper and lower parts of the tree was observed. This is in agreement with findings of a chilling temperature effect in dormancy release, which appears to play a key role in synchronisation of development of buds in a plant (Fuchigami and Nee, 1987; Cook and Jacobs, 1999). This effect was not clear in 'Golden Delicious' in 2002 and 2003. In 2002, there was a high influence of concentration for both RB treatments, where the higher concentrations of HC-oil and TDZ-oil extended the flowering period and generally reduced the flowering gradient in the upper branch. In 2003, the bloom of upper and lower branches was naturally synchronized as observed in the control treatment trees (Table 4). Siller-Cepeda *et al.* (1992) reported that applications of HC after chilling satisfaction had no effect on promoting bud break, and rather than enhancing bud break, HC reduced and delayed bud growth and injured the buds and stems. Similar results have been reported for other species when cyanamide was applied during eco-dormancy (Fuchigami and Nee, 1987). During this stage, HC was no longer effective in promoting bud break. HC either inhibited bud growth or several injured the quiescent buds stems (Nee, 1986, cit. Fuchigami and Nee, 1987). In 'Royal Gala' in 2002 the higher rate of HC increased the flowering period and reduce the flowering gradient in the lower branch. This could have been due to a late application and therefore to a more developed buds stage, since in 2002 the winter was cooler (906 Richardson chilling units since the 1st of May) compared to the other years of study.

Rest-breaking treatments can only compensate for part of the chilling requirement (Erez, 1987; Fuchigami and Nee, 1987; Steffens and Stutte, 1989; Faust *et al.*, 1997). Furthermore, the chilling quality appears to play an important role; high temperatures reduce CU efficacy (Erez *et al.*, 1979; Erez and Couvillon, 1987). In this study on 'Golden Delicious', the 2001 application was performed late (26 Sept.) when more CU had accumulated, but the HU from that time to 50% bloom were similar to those in 2002. This could be explained since the 2002 winter was cooler (871 CU, from 1 May to 31 Aug.), and in 2001 the earlier high temperatures in September could have been counteracting the CU effect. However, there was a difference of 20 days in the spray time, and a difference of about 15 days in the 50% bloom (10-22 Oct in 2001 and 2-5 Oct in 2002). A similar situation was observed for 'Gala', although the GDH for 50% bloom was less in 2003 compared to 'Golden Delicious'. The counteracting effect of high temperature on the CU accumulation has been documented (Richardson *et al.*, 1974; Erez, 1987; Linsley-Noakes *et al.*, 1994; Erez, 2000; El-Agamy *et al.*, 2001).

The bloom period appears to be more compressed in 2001 and 2003, compared to 2002. In this year, trees could have been in a more advanced stage of dormancy since the winter was cooler. HC inhibiting bud growth have been reported when applied during eco-dormancy (Nee, 1986, cit. Fuchigami and Nee, 1987; Fuchigami and Nee, 1987; Siller-Cepeda *et al.*, 1992; Bound and Jones, 2004). A delayed growth of the more developed buds could explain the fact that the HC treatments did not compress blossom in 2002, even high rates of HC increased bloom period compared to the lower rates. With respect to TDZ-oil application, it was also observed an extended flowering period in 2002 with higher rates. This could have been due also to a phototoxic effect of a high rate on those more developed buds. There is no previous information about the effect of TDZ on flowering period of TDZ in eco-dormant buds or in trees which have been exposed to prolonged winter chilling (Wang *et al.*, 1986b; Wang *et al.*, 1987; Bondok *et al.*, 1995). Generally, RB treatments seem to have been more effective in compressing the flowering period in years when winter chilling was less. However, in the case of 2003 where both the winter and spring were warmer, rest-breaking treatment in some cases had also advanced bloom. Besides the compensation effect for the lack of chilling, high spring temperatures also play an important role in blossom duration, concentrating it and in some cases advancing it. The warmer spring in 2003 resulted in a flowering period that was considerably shorter than those seen in the other years in the control treatment. Similar results were observed by Bound and Jones (2004) who found that in 'Fuji' apples with their chilling requirements fully satisfied, HC could still be used to bring flowering forward but not necessarily to compress the flowering period.

A compressed blossom may result in the need for modifications in chemical thinning programmes. According to Bound and Jones (2004), when HC is combined with an effective thinning programme, the advancement of flowering may have a positive effect on fruit size. Although this aspect requires further study, the authors suggest that possibly earlier bloom will enable trees to carry a larger crop. However, it has to be considered that a compressed flowering may exacerbate the thinning effect.

In this study, it was also noticed that there was a good synchronisation between the two cultivars. This is relevant since these two cultivars are often used as cross pollinators in many orchards. This result is in agreement with the results of Jackson and Bepete (1995) when using HC to break dormancy in apples under sub-optimal winter chilling.

In ‘Golden Delicious’, over the three years of study, there were some symptoms of phytotoxicity after the 0.98% HC + 4% oil treatment, such as deformed small flowers on the terminal position and on three-year or older wood (data not shown). Many authors have observed that later and higher HC rates cause a greater response in bud burst, but also more phytotoxicity (Samish, 1954; Saure, 1985; Shulman *et al.*, 1986; Erez, 1987; Siller-Cepeda *et al.*, 1992; Fallahi *et al.*, 1992; Lee, 1994; Erez, 2000; Bound and Jones, 2004). Time of application appears to be crucial where the spring is warm, since heat stimulate growth and in some extend may compensate for the lack of chilling (Erez, 2000), therefore buds could be in a more developed and sensitive stage. As described by Erez (2000), flower buds are more sensitive than other tree organs to most of the dormancy-breaking chemicals, and this sensitivity is manifested in flower bud phytotoxicity and loss of flowers. Reduced fruit set after the 1.96% HC + 4% oil treatment has been observed in ‘Golden Delicious’, probably due to a phytotoxic effect (Paper 1).

With the TDZ-oil treatment, abnormalities were observed on the flowers as well as shoots, particularly at the 6% rate on ‘Golden Delicious’. Some flowers, mainly on three-year or older wood, had shorter and thicker receptacles and pedicels, and small petals (data not shown). 3% and 5% TDZ-oil applied to ‘Royal Gala’ and 4% and 6% TDZ-/oil applied to ‘Golden Delicious’ in 2002, resulted in very high rates of bud burst on one-year-old shoots and some spurs. Bud burst at the bud scar ring and at the base of bud scars on 2-year-old wood, and the consequent growth of abnormal small leaves (see Figure 9), was observed in the 2002 treatment of GD (data not shown). Regarding the TDZ effect, Alvarado-Raya *et al.* (2000) proved that TDZ was as effective as HC in advancing the beginning of flowering and full bloom, and in compressing the time between these two stages in ‘Shiro’ plum. When TDZ was applied at a concentration of 100 mg L⁻¹, 17 days

before full bloom, the ovary diameter and the thickness of the ovary wall in the flower bud increased (compared with the other treatments) (Alvarado-Raya *et al.*, 2000). In the present study, there could have been interaction between the rate of TDZ application and the development stage of reproductive buds at the spraying time, resulting in increased cellular division and enlargement and, subsequently, abnormal flowers.

Conclusion

To conclude, rest-breaking treatments are necessary to compensate for lack of adequate winter chilling and advance bloom, but this effect is not always evident when the spring is warm. In general, 0.245% HC + 4% oil was less effective than 0.49% HC + 4% oil in increasing bud burst in 'Gala' apples. However, the higher rate may delay bud burst in some years due to phytotoxic effect of HC when buds are in a more advance stage of development. Both 0.49% HC + 4% oil and 0.98% HC + 4% oil were able to improved bud break in 'Golden Delicious' in 2001 and 2003, but not in 2002. Both treatments were effective in compressing and synchronising flowering in 2001, but our data show that late application can induce phytotoxicity. TDZ-oil was very effective for increasing bud burst, and also effective at 5% for concentrating flowering in 'Royal Gala' in 2002 and 2003. However, it appears that after a cooler winter, 6% TDZ-oil could result in an exacerbated bud burst effect with excessive vegetative growth, as was observed in 2002 for 'Golden Delicious'. The implications for chemical thinning treatments must be considered.

After a mild winter or when a warm spring is forecasted and a certain amount of chilling has been satisfied, it is better not to wait for more CU accumulation during late winter before applying the rest-breaking treatment. This will avoid damage to the reproductive buds and will ensure effectiveness with regard to the advancement and compression of bud burst.

Literature Cited

- Alvarado-Raya, H., Rodríguez-Alcázar, J., Calderón-Zavala, G. and Cárdenas-Zoriano, E., 2000. Thidiazuron, flower budbreak and ovary dimensions in Japanese plum (*Prunus salicina* L.) 'Shiro'. *Agrociencia* 34: 321-327.
- Bangerth, F., 1986. Thinning of apple fruits and relations to endogenous hormones. *Acta Horticulturae* 179: 605-612.
- Bangerth, F., 1989. Dominance among fruits/sinks and the search for a correlative signal. *Physiologia Plantarum* 76: 608-614.

- Bondok, M.A., Abdel-Hamid, N. and El-Wakeel, H.F., 1995. Bud break, fruit maturity and yield of "Anna" apple as influenced by plant bioregulator "Thidiazuron". *Annals of Agricultural Science (Cairo)* 40: 343-358.
- Bound, S.A. and Jones, K.M., 2004. Hydrogen cyanamide impacts on flowering, crop load, and fruit quality of red 'Fuji' apple (*Malus domestica*). *New Zealand Journal of Crop and Horticultural Science* 32: 227-234.
- Bubán, T. and Faust, M., 1982. Flower bud induction in apple trees: Internal control and differentiation. *Horticultural Reviews* 4: 174-203.
- Chandler, W.H., 1960. Some studies of rest in apple trees. *Proceeding of the American Society for Horticultural Science* 76: 1-10.
- Cook, N.C. and Jacobs, G., 1999. Sub-optimal winter chilling Impedes development of acrotony in apple shoots. *HortScience* 34: 1213-1216.
- Cook, N.C., Rabe E, Keulemans, J. and Jacobs, G., 1998. The expression of acrotony in deciduous fruit trees: a study of the apple rootstock M9. *Journal of the American Society for Horticultural Science* 123: 30-34.
- Crabbé, J.J., 1984. Correlative effects modifying the course of bud dormancy in wood plants. *Zeitschrift fuer Pflanzenphysiologie* 113: 167-172.
- El-Agamy, S.Z., Mohamed, A.K.A., Mostafa, F.M.A. and Abdallah, A.Y., 2001. Chilling and heat requirements for budbreak and fruiting of 'Anna' and 'Dorsett Golden' apple cultivars under warm climate. *Acta Horticulturae* 565: 103-108.
- El-Kassas, S.E., El-Sese, M.A., El-Salhy, A.M. and El-Wasfy, M.M., 1996. Physiological studies on flowering, fruit setting and bearing habits of some apple cultivars under Assiut environment. *Assiut Journal of Agricultural Sciences* 27: 3-21(abstract).
- Erez, A., 1979. The effect of temperature on the activity of oil + dinitro-o-cresol sprays to break the rest of apple buds. *HortScience* 14: 141-142.
- Erez, A., 1987. Chemical control of budbreak. *HortScience* 22: 1240-1243.
- Erez, A. 2000. Bud dormancy; phenomenon, problems and solutions in the tropics and subtropic. In: Erez, A. (Ed.), *Temperate fruit crops in warm climate*, pp. 17-48. Bet-Dagan: Kluwer Academic Publishers. 48 pp.
- Erez, A. and Couvillon, G.A., 1987. Characterization of the influence of moderate temperatures on rest completion in peach. *Journal of the American Society for Horticultural Science* 112: 677-680.
- Erez, A., Couvillon, G.A. and Hendershott, C.H., 1979. The effect of cycle length on chilling negation by high temperatures in dormant peach leaf buds. *Journal of the American Society for Horticultural Science* 101: 573-576.
- Fallahi, E., Simons, B.R., Fellman, J.K. and Colt, W.M., 1992. Use of hydrogen cyanamide for apple and plum thinning. *Plant Growth Regulation* 11: 435-439.

- Faust, M., Erez, A., Rowland, L.J., Wang, S.Y. and Norman, H.A., 1997. Bud dormancy in perennial fruit trees: physiological basis for dormancy induction, maintenance, and release. *HortScience* 32: 623-629.
- Faust, M., Millard, M.M. and Stutte, G.W., 1991. Bound versus free water in dormant apple buds—a theory for endodormancy. *HortScience* 26: 887-890.
- Fuchigami, L.H. and Nee, C.C., 1987. Degree growth stage model and rest-breaking mechanism in temperate woody perennials. *HortScience* 22: 836-845.
- Gruber, J. and Bangerth, F., 1990. Diffusible IAA and dominance phenomena in fruit of apple and tomato. *Physiologia Plantarum* 79: 354-358.
- Hauagge, R. and Cummins, J.N., 1991. Phenotypic variation of length of bud dormancy in apple cultivars and related *Malus* species. *Journal of the American Society for Horticultural Science* 116: 100-106.
- Jackson, J.E. and Bepete, M., 1995. The effect of hydrogen cyanamide (Dormex) on flowering and cropping of different apple cultivars under tropical conditions of sub-optimal winter chilling. *Scientia Horticulturae* 60: 293-304.
- Lee, R.R., 1994. Interrelationships between flowering habit, fruit characteristics, hydrogen cyanamide applications, and xylem cytokinin levels in 'Rome Beauty' apples (*Malus domestica* Bork.). University of Idaho.
- Linsley-Noakes, G.C., Allan, P. and Matthee, G., 1994. Modification of rest completion prediction models for improved accuracy in south african stone fruits orchards. *Journal of the Southern African Society for Horticultural Sciences* 4: 13-15.
- Luckwill, L.C. 1974. A new look at the process of fruit bud formation in Apple. In: Antoszewski, R., Harrison, L. & Nowosielski, J. (Eds.), *Proceedings of the 19th international horticultural congress*, pp. 237-245. Warszawa: 245 pp.
- North, M., 1989. Effect of cyanamide and DNOC/oil on budbreak, yield and fruit size of Golden Delicious apples. *South African Journal of Plant and Soil* 6: 176-178.
- Pérez, F.J. and Lira, W., 2005. Possible role of catalase in post-dormancy bud break in grapevines. *Journal of Plant Physiology* 162: 301-308.
- Richardson, E.A., Seeley, S.D. and Walker, D.R., 1974. A model for estimating the completion of rest for 'Redhaven' and 'Elberta' peach trees. *HortScience* 9: 331-332.
- Richardson, E.A., Seeley, S.D., Walker, D.R., Anderson, J.L. and Ashcroft, G.L., 1975. Phenoclimatology of spring peach bud development. *HortScience* 10: 236-237.
- Samish, R.M., 1954. Dormancy in woody plants. *Annual Review of Plant Physiology* 5: 183-204.
- Saure, M.C., 1985. Dormancy release in deciduous fruit trees. *Horticultural Reviews* 7: 239-300.
- Shulman, Y., Nir, G. and Lavee, S., 1986. Oxidative processes in bud dormancy and the use of hydrogen cyanamide in breaking dormancy. *Acta Horticulturae* 179: 141-148.

- Siller-Cepeda, J.H., Fuchigami, L.H. and Chen, T.H.H., 1992. Hydrogen cyanamide-induced budbreak and phytotoxicity in 'Redhaven' peach buds. *HortScience* 27: 874-876.
- Steffens, G.L. and Stutte, G.W., 1989. Thidiazuron substitution for chilling requirement in three apple cultivars. *Journal of Plant Growth Regulation* 8: 301-307.
- Stockert, T. and Stösser, R., 1996. Blütenqualität und Ertrag beim Apfel. *Erwerbobstbau* 38: 170-173.
- Wang, S.Y., Ji, Z.L., Sun, T. and Faust, M., 1987. Effect of thidiazuron on abscisic acid content in apple bud relative to dormancy. *Physiologia Plantarum* 71: 105-109.
- Wang, S.Y., Steffens G.L. and Faust, M., 1986a. Breaking bud dormancy in apple with a plant bioregulator, thidiazuron. *Phytochemistry* 25: 311-317.
- Wang, S.Y., Steffens G.L. and Faust, M., 1986b. Breaking bud dormancy in apple with a plant bioregulator, thidiazuron. *Phytochemistry* 25: 311-317.

Table 1. Reproductive and vegetative bud burst in 'Golden Delicious' apples measured as percentage of total buds per branch in 2001 and as number of burst buds per centimetres (cm) of branch circumference in 2002 and 2003.

Treatments	Bud burst 2001 (> one-year-old wood)		
	Total	Reproductive proportion (%)	Vegetative proportion
Control	39.8 b ^y	17.7 n.s.	82.3
DNOC-oil 6%	65.2 a	22.3	77.7
HC 0.49% + oil 4%	60.8 a	19.2	80.9
HC 0.98% + oil 4%	61.8 a	15.4	84.6
Pr>F	0.0062	0.5909	0.5909

Treatments	Bud burst (number of burst buds/cm branch circumference)			
	2002		2003	
	Reproductive	Vegetative	Reproductive	Vegetative
Control	3.49 n.s.	4.29 b	0.92 n.s.	4.91 b
HC 0.49% + oil 4%	4.03	7.35 b	2.57	19.07 a
HC 0.98% + oil 4%	2.99	7.03 b	1.07	15.22 a
TDZ-oil 4%	4.09	12.22 a	1.87	17.50 a
TDZ-oil 6%	3.94	16.29 a	2.64	14.68 a
Pr>F	0.2212	0.0017	0.1848	0.0069

^y Means within each column with the same letter are not significantly different at $p \leq 0.05$
n.s. = no significant differences.

Table 2. Blooming period, flowering gradient, and days and GDH (°C) to 50% bloom (percentage of clusters at full bloom), according to wood age. Values obtained from the logistic curve fitting for cv. Golden Delicious (2001).

Treatments ^w	Blooming period from 10% to 90% blossom (days)	Flowering gradient	Days to 50% blossom (DAS) ^x
		<u>1-year-old wood</u>	
Control	24.6 a ^y	0.216 b	28.6 ab (7,783 ^z)
DNOC-oil 6%	14.3 ab	0.396 a	25.7 b (7,023)
HC 0.49% + oil 4%	11.8 b	0.397 a	25.5 b (7,023)
HC 0.98% + oil 4%	16.7 ab	0.337 ab	29.0 a (7,783)
Pr>F	0.0263	0.0115	0.0271
		<u>>1-year-old wood</u>	
Control	16.6 a	0.265 b	24.6 ab (6,693)
DNOC-oil 6%	9.7 b	0.450 a	23.2 b (6,025)
HC 0.49% + oil 4%	11.5 b	0.419 a	24.1 ab (6,326)
HC 0.98% + oil 4%	10.4 b	0.411 a	25.7 a (7,023)
Pr>F	0.0007	0.0362	0.1154
		<u>Total</u>	
Control	19.9 a	0.249 b	26.8 a (7,288)
DNOC-oil 6%	9.6 b	0.431 a	23.6 b (6,326)
HC 0.49% + oil 4%	10.0 b	0.408 a	23.7 b (6,326)
HC 0.98% + oil 4%	11.2 b	0.369 a	26.5 a (7,288)
Pr>F	0.0027	0.0325	0.0080

^w 955 Chilling units accumulated from 1 May until treatment application (26 Sept.)

^x DAS = days after spraying

^y Means within each column with the same letter are not significantly different at $p \leq 0.05$

^z Estimated growing degree hours from treatment application time until 50% bloom, in brackets.

Table 3. Blooming period, flowering gradient, days and GDH (°C) to 50% bloom (percentage of clusters at full bloom), according to branch position. Values obtained from the logistic curve fitting for cv. Golden Delicious (2002).

Treatments ^w	Blooming period from 10% to 90% blossom (days)	Flowering gradient	Days to 50% blossom (DAS) ^x
<u>Upper branch</u>			
Control	14.2 abc ^y	0.332 b	31.6 n.s. (7,477 ^z)
HC 0.49% + oil 4%	6.3 c	0.723 a	32.5 (7,758)
HC 0.98% + oil 4%	18.6 a	0.278 b	29.9 (6,821)
TDZ-oil 4%	9.8 bc	0.602 ab	32.5 (7,758)
TDZ-oil 6%	17.3 ab	0.270 b	32.8 (7,758)
Pr>F	0.0524	0.0385	0.4153
<u>Lower branch</u>			
Control	13.9 n.s.	0.320 n.s.	27.0 a (6,170)
HC 0.49% + oil 4%	13.9	0.328	28.6 a (6,591)
HC 0.98% + oil 4%	13.8	0.328	24.8 b (5,884)
TDZ-oil 4%	13.9	0.324	28.8 a (6,591)
TDZ-oil 6%	13.8	0.322	27.6 a (6,365)
Pr>F	0.9999	0.9967	0.0249

^w 906 chilling units accumulated from 1 May until treatment application (7 Sep.)

^x DAS = days after spraying

^y Means within each column with the same letter are not significantly different at $p \leq 0.05$

^z Estimated growing degree hours from treatments application time until 50% bloom, in brackets

n.s. = no significant differences.

Table 4. Blooming period, flowering gradient, days and GDH (°C) to 50% bloom (percentage of open flowers) according to branch position. Values obtained from the logistic curve fitting for cv. Golden Delicious (2003).

Treatments ^w	Blooming period from 10% to 90% blossom (days)	Flowering gradient	Days to 50% blossom (DAS) ^x
<u>Upper branch</u>			
Control	7.1 ab ^y	0.680 b	40.0 a (10,250) ^z
HC 0.49% + oil 4%	7.2 a	0.643 b	38.5 bc (10,049)
HC 0.98% + oil 4%	7.6 a	0.671 b	37.9 c (9,811)
TDZ-oil 4%	4.8 b	0.941 a	39.3 ab (10,049)
TDZ-oil 6%	4.6 b	0.993 a	39.0 ab (10,049)
Pr>F	0.0400	0.0111	0.0029
<u>Lower branch</u>			
Control	8.5 n.s.	0.753 n.s.	41.6 a (10,660)
HC 0.49% + oil 4%	7.8	0.737	37.5 c (9,811)
HC 0.98% + oil 4%	8.0	0.694	37.7 c (9,811)
TDZ-oil 4%	6.0	0.967	39.4 b (10,049)
TDZ-oil 6%	5.2	0.892	38.0 bc (9,811)
Pr>F	0.3767	0.1623	0.0005

^w 832 chilling units accumulated from 1 May until treatment application (15 Sept.)

^x DAS = days after spraying

^y Means within each column with the same letter are not significantly different at $p \leq 0.05$.

^z Estimated growing degree hours from treatments application time until 50% bloom, in brackets

n.s. = no significant differences.

Table 5. Reproductive and vegetative bud burst in 'Royal Gala' apples measured as a percentage of total buds per branch in 2001 and as the number of burst buds per cm of branch circumference in 2002 and 2003.

Treatments	Bud burst 2001 (> 1-year-old wood)		
	Total	Reproductive proportion (%)	Vegetative proportion
Control	54.6 b ^y	37.9 n.s.	62.1
DNOC/oil 6%	92.6 a	37.2	62.8
HC 0.245 % + oil 4%	92.9 a	39.3	60.7
HC 0.49 % + oil 4%	83.3 a	38.9	61.1
Pr>F	0.0001	0.9768	0.9768

Treatments	Bud burst (number of burst buds/cm branch circumference)			
	2002		2003	
	Reproductive	Vegetative	Reproductive	Vegetative
Control	2.92 n.s.	8.51 b	9.14 n.s.	4.34 n.s.
HC 0.245 % + oil 4%	2.86	8.71 b	8.45	5.01
HC 0.49 % + oil 4%	2.08	16.21 a	9.04	4.92
TDZ-oil 3%	3.47	17.59 a	9.44	5.05
TDZ-oil 5%	3.18	19.28 a	12.19	6.27
Pr>F	0.4316	0.0007	0.2647	0.2331

^y Means within each column with the same letter are not significantly different at $p \leq 0.05$

n.s. = no significant differences

Table 6. Blooming period, flowering gradient, and days and GDH (°C) to 50% bloom (percentage of clusters at full bloom), according to wood age. Values obtained from the logistic curve fitting for cv. Royal Gala (2001).

Treatments ^w	Blooming period from 10% to 90% blossom (days)	Flowering gradient	Days to 50% blossom (DAS) ^x	
<u>1-year-old wood</u>				
Control	10.8 n.s.	0.428 n.s.	32.0 n.s.	(8,078 ^z)
DNOC-oil 6%	15.4	0.384	33.9	(8,560)
HC 0.245% + oil 4%	6.9	0.597	30.2	(7,381)
HC 0.49% + oil 4%	8.3	0.430	31.0	(7,748)
Pr>F	0.3991	0.5001	0.2629	
<u>>1-year-old wood</u>				
Control	14.9 a ^y	0.365 b	34.0 a	(8,560)
DNOC-oil 6%	6.2 b	0.920 a	31.4 b	(7,748)
HC 0.245% + oil 4%	7.9 b	0.897 a	31.0 b	(7,748)
HC 0.49% + oil 4%	3.7 b	1.248 a	30.2 b	(7,381)
Pr>F	0.0098	0.0053	0.0242	
<u>Total</u>				
Control	14.6 a	0.355 b	33.9 a	(8,560)
DNOC-oil 6%	6.7 b	0.875 a	31.1 b	(7,748)
HC 0.245% + oil 4%	7.5 b	0.844 a	30.6 b	(7,748)
HC 0.49% + oil 4%	3.8 b	1.196 a	30.2 b	(7,381)
Pr>F	0.0071	0.0053	0.0019	

^w 938 Chilling units accumulated from 1 May until treatment application (20 Sep.)

^x DAS = days after spraying

^y Means within each column with the same letter are not significantly different at $p \leq 0.05$.

^z Estimated growing degree hours from treatments application time until 50% bloom, in brackets

n.s.= no significant differences.

Table 7. Blooming period, flowering gradient, days and GDH (°C) to 50% bloom (percentage of clusters at full bloom), according to branch position. Values obtained from the logistic curve fitting for cv. Royal Gala (2002).

Treatments ^w	Blooming period from 10% to 90% blossom (days)	Flowering gradient	Days to 50% blossom (DAS) ^x
<u>Upper branch</u>			
Control	13.0 n.s.	0.346 c ^y	33.3 n.s. (7,336 ^z)
HC 0.245% + oil 4%	9.8	0.462 ab	31.9 (7,141)
HC 0.49% + oil 4%	9.8	0.528 a	33.2 (7,336)
TDZ-oil 3%	11.3	0.433 abc	31.6 (7,141)
TDZ-oil 5%	11.3	0.361 b	32.0 (7,141)
Pr>F	0.1817	0.0475	0.6566
<u>Lower branch</u>			
Control	12.6 ab	0.37 b	31.0 n.s. (6,971)
HC 0.245% + oil 4%	7.5 d	0.67 a	31.0 (6,971)
HC 0.49% + oil 4%	14.1 a	0.33 b	31.0 (6,971)
TDZ-oil 3%	10.3 bc	0.46 b	31.1 (6,971)
TDZ-oil 5%	8.5 cd	0.54 ab	30.5 (6,971)
Pr>F	0.0005	0.0285	0.9758

^w 875 Chilling units accumulated from 1 May until treatment application (2 Sept.)

^x DAS = days after spraying

^y Means within each column with the same letter are not significantly different at $p \leq 0.05$

^z Estimated growing degree hours from treatments application time until 50% bloom, in brackets

n.s. = no significant differences.

Table 8. Blooming period, flowering gradient, days and GDH (°C) to 50% bloom (percentage of open flowers) according to branch position. Values obtained from the logistic curve fitting for cv. Royal Gala (2003).

Treatments ^w	Blooming period from 10% to 90% blossom (days)	Flowering gradient	Days to 50% blossom (DAS) ^x
<u>Upper branch</u>			
Control	10.6 a ^y	0.427 n.s.	36.4 a (9,239 ^z)
HC 0.245% + oil 4%	5.9 b	0.872	34.1 bc (8,544)
HC 0.49% + oil 4%	5.9 b	0.841	33.2 c (8,275)
TDZ-oil 3%	7.9 ab	0.566	35.5 ab (9,239)
TDZ-oil 5%	8.1 ab	0.740	34.3 bc (8,544)
Pr>F	0.0115	0.1477	0.0256
<u>Lower branch</u>			
Control	11.6 a	0.40 b	33.9 n.s. (8,544)
HC 0.245% + oil 4%	7.6 b	0.62 a	33.0 (8,275)
HC 0.49% + oil 4%	7.6 b	0.61 a	32.9 (8,275)
TDZ-oil 3%	8.3 b	0.55 a	34.6 (8,851)
TDZ-oil 5%	8.5 b	0.53 a	33.8 (8,544)
Pr>F	<0.0001	0.0007	0.1615

^w 832 chilling units accumulated from 1 May until treatment application (15 Sept.)

^x DAS = days after spraying

^y Means within each column with the same letter are not significantly different at $p \leq 0.05$

^z Estimated growing degree hours from treatments application time until 50% bloom, in brackets.

n.s. = no significant differences.

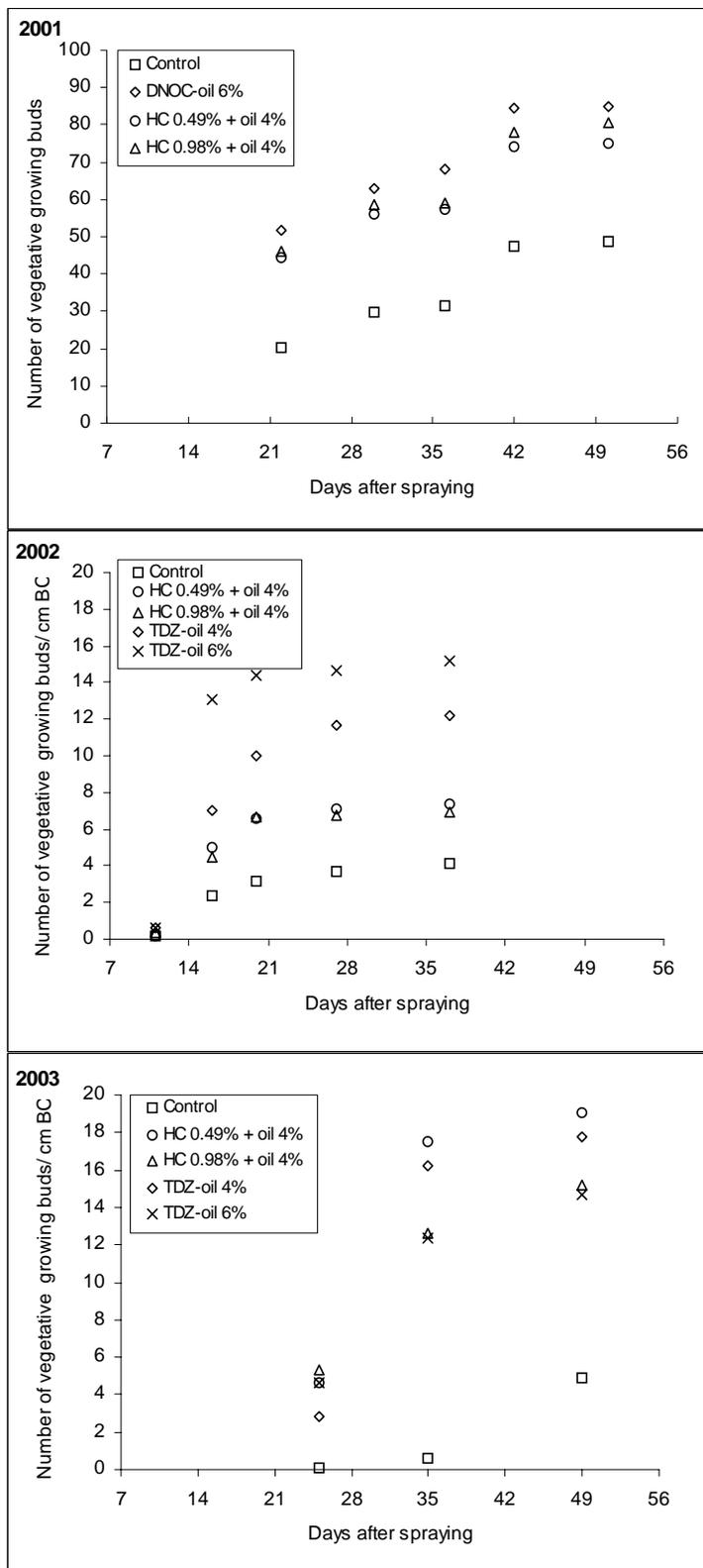


Figure 1. Vegetative bud burst for 'Golden Delicious' apple trees, as the number of growing vegetative buds (> 1-year-old wood) on two branches per tree (2001) and as the number of growing vegetative buds per centimetre of branch circumference (BC) on one lower branch per tree (2002 and 2003).

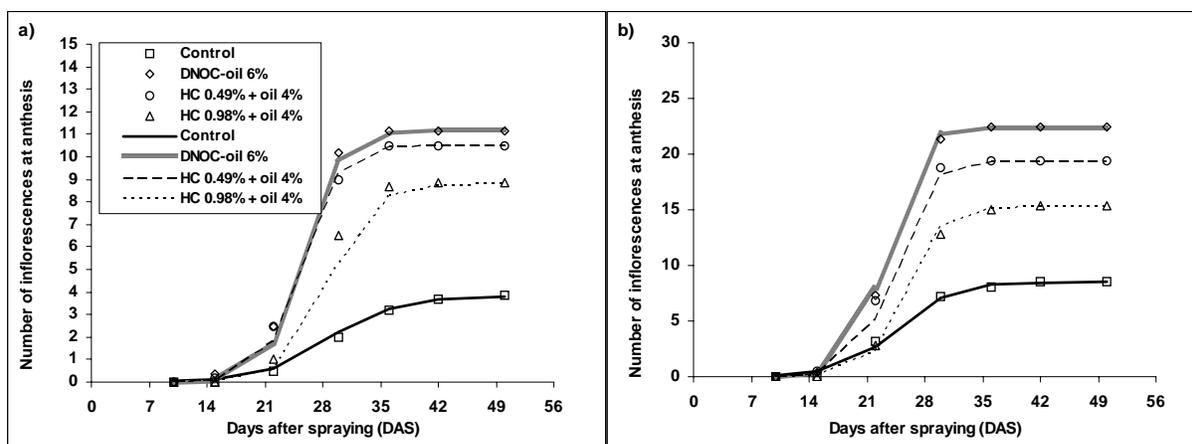


Figure 2. Blooming period for 'Golden Delicious' apple trees in 2001, as accumulated blossom clusters (open symbols) and estimated values (lines) obtained from the logistic curve fitting: a) one-year-old wood and b) older wood.

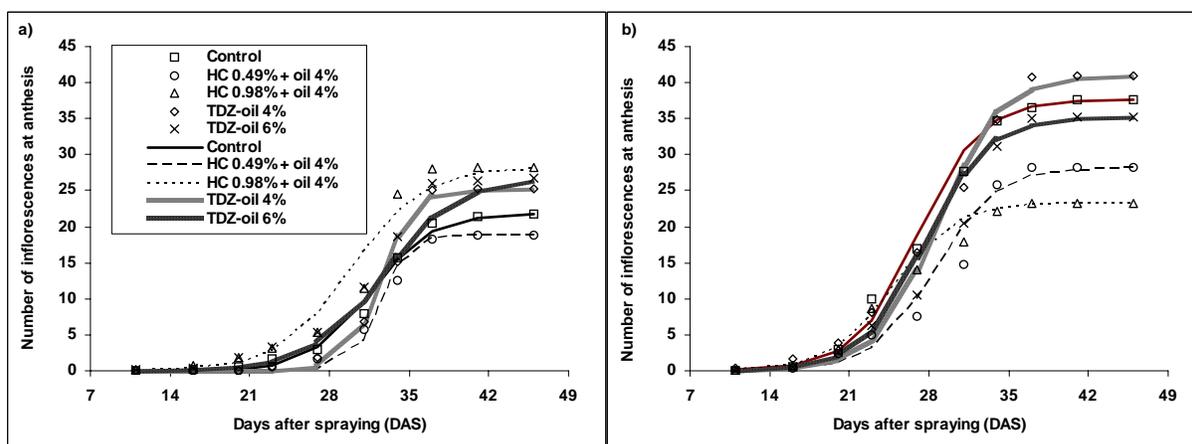


Figure 3. Blooming period for 'Golden Delicious' apple trees in 2002, as accumulated blossom clusters (open symbols) and estimated values (lines) obtained from the logistic curve fitting in: a) the upper branch and b) the lower branch.

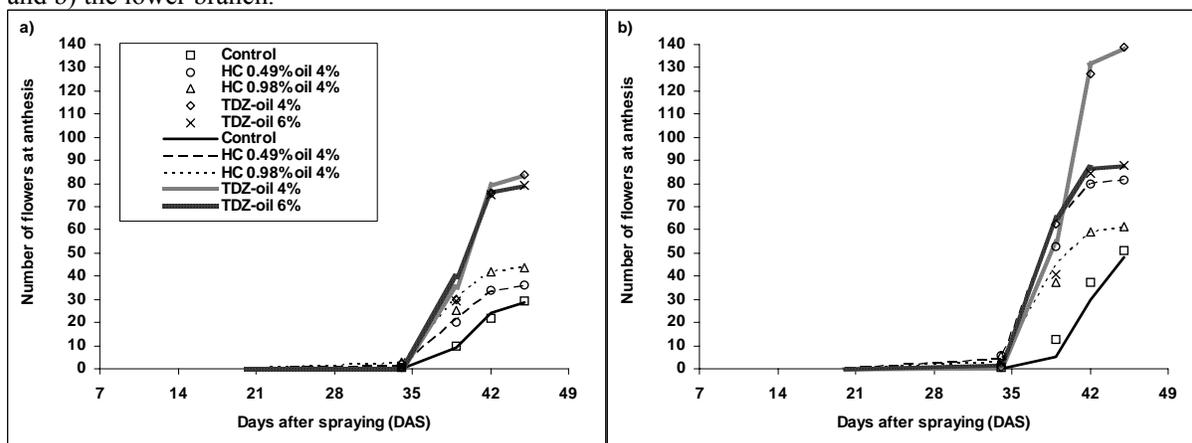


Figure 4. Blooming period for 'Golden Delicious' apple trees in 2003, as accumulated open flowers (open symbols) and estimated values (lines) obtained from the logistic curve fitting: a) the upper branch and b) the lower branch.

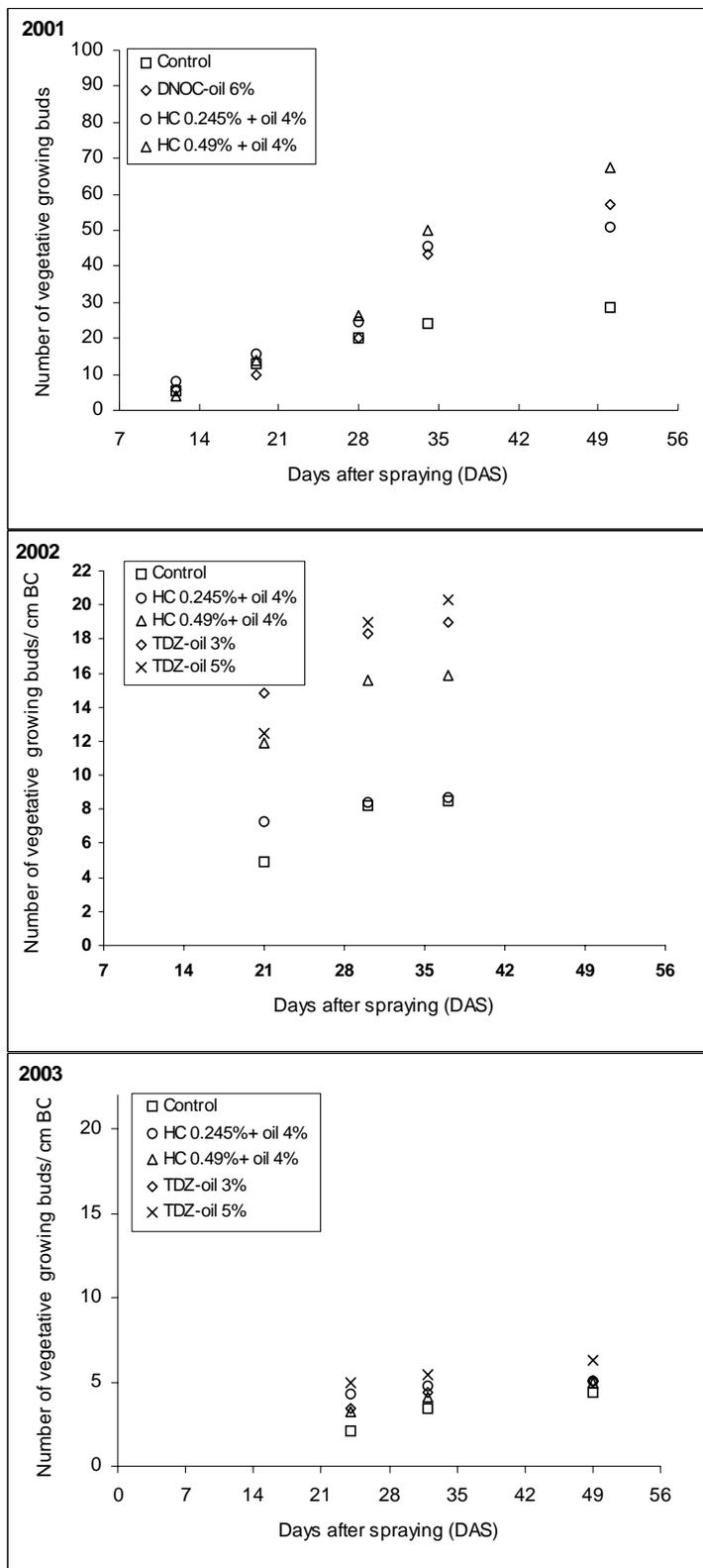


Figure 5. Vegetative bud burst for 'Royal Gala' apple trees, as the number of growing vegetative buds (> one-year-old wood) on two branches per tree in 2001 and as the number of growing vegetative buds per centimetre of branch circumference (BC) on one lower branch per tree for in 2002 and 2003.

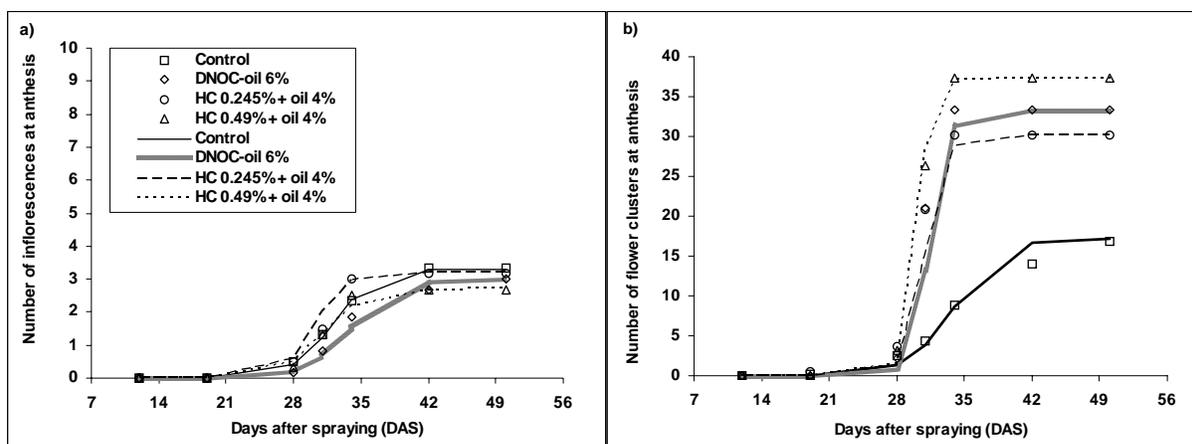


Figure 6. Blooming period for 'Royal Gala' apple trees in 2001, as accumulated blossom clusters (open symbols) and estimated values (lines) obtained from the logistic curve fitting in: a) one-year-old wood and b) older wood.

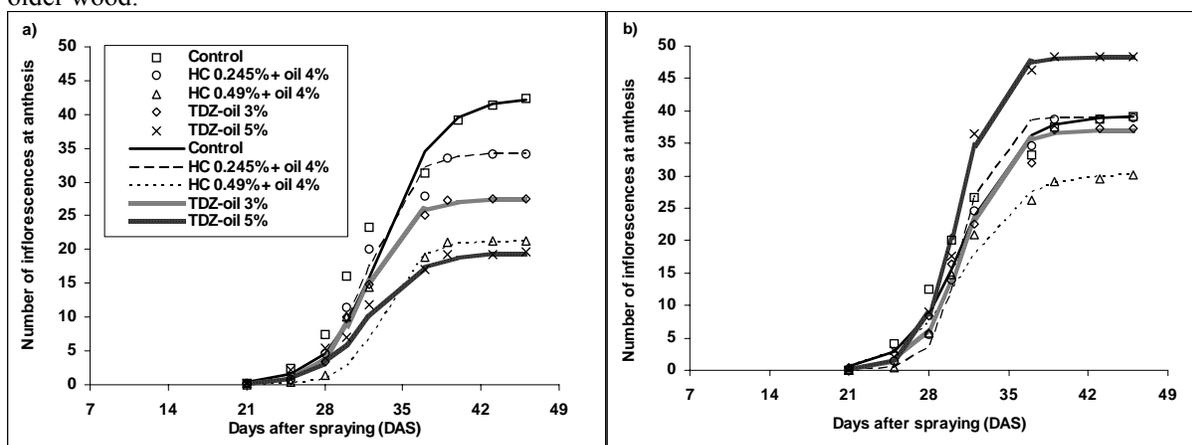


Figure 7. Blooming period for 'Royal Gala' apple trees in 2002, as accumulated blossom clusters (open symbols) and estimated values (lines) obtained from the logistic curve fitting in: a) the upper branch and b) the lower branch.

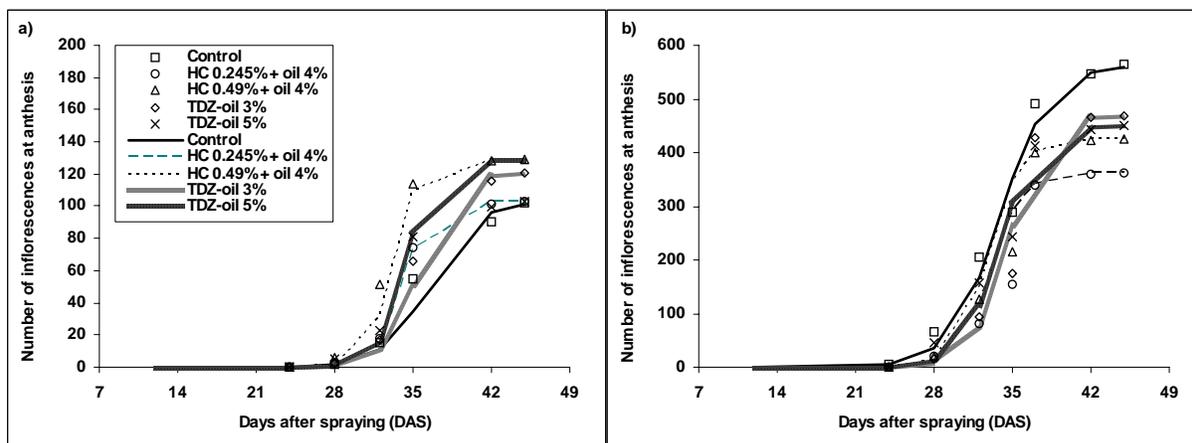


Figure 8. Blooming period for 'Royal Gala' apple trees in 2003, as accumulated open flowers (open symbols) and estimated values (lines) obtained from the logistic curve fitting in: a) the upper branch and b) the lower branch.



Figure 9. Abnormal bud burst in 'Golden Delicious' apple trees after TDZ-oil (Lift) application. a) Bud burst on the bud scar ring and b) bud swell on scars at the base of buds on two-year-old wood.

PAPER 3: Influence of rest breaking treatments on fruit set and yield of apple trees in insufficiently chilled trees

Summary

Chemical treatments that hasten budburst and bloom may have variable effects on fruit set. This is partly because of the variability in the type of product and phytotoxicity. In South Africa, most apple producing areas receive insufficient chilling to break dormancy, and an annual application of a chemical rest breaking (RB) treatment is included as standard practice in such areas. Hydrogen cyanamide (HC) became the replacement for dinitro-o-cresol (DNOC) upon its withdrawal from the market. HC has been effective for the dormancy release of apple trees but variable effects on yield, fruit quality, fruit set and blooming period have been observed. Thidiazuron (TDZ) has shown the capacity to release lateral buds from dormancy in apple and it reduced the number of chilling units required to achieve bud break. In this paper we report on the effect of DNOC-oil, HC and TDZ plus oil on budburst, fruit set, yield and return bloom on mature apple trees (*Malus domestica* Borkh.), under marginal winter chilling conditions. The research was carried out in the Elgin area (34°S, 300 m), South Africa, over a period of three years. All the experimental sites were commercial orchards. In 2001, the effect of HC was compared to that of a mixture of DNOC and oil. The treatments were: HC as Dormex® (49% v/v HC) at two rates, 0.245% and 0.49% v/v for 'Royal Gala' and 0.49% and 0.98% for 'Golden Delicious', in combination with oil at 4%; 6% DNOC-oil (DNOC 3% + mineral oil 72% v/v); and one unsprayed control. The 2002 and 2003 trials included HC plus oil and TDZ-oil. Treatments consisted of HC at the same two concentrations used the previous year in combination with oil at 4% for both cultivars; TDZ-oil as Lift® (TDZ 3 g·L⁻¹, oil + adjuvants) at two concentrations, namely 3% and 5% for 'Royal Gala' and 'Ruby Gala' and 4% and 6% for 'Golden Delicious'. There was one unsprayed control for each cultivar. Budburst, fruit set, return bloom and yield were assessed. HC plus oil and TDZ-oil are effective treatments to break dormancy in apple trees in warm winter areas. High rates of HC, namely 0.49% for 'Gala' and 0.98% for 'Golden Delicious' in a mix with oil at 4%, could however reduce fruit set. The effect of TDZ-oil on fruit set and yield was variable. Yield could possibly be increased by TDZ-oil applications. Return bloom the following spring was reduced, when applied at 5% in 'Royal Gala'. Malformation of the calyx cavity appears to be the main problem of this cytokinin-like compound in 'Golden Delicious' apples. Hence, the time of application is crucial and an optimal time has to be established.

Keywords: apple, fruit set, hydrogen cyanamide, rest-breaking treatment, thidiazuron, yield

Introduction

In cold climates, the winter chilling requirements of temperate trees is a survival mechanism. Trees enter a state of endo-dormancy in which endogenous factors keep the trees from growing even if environmental factors become favourable for a short time (Lang *et al.*, 1985). Fulfilment of the chilling requirements is a prerequisite for deciduous fruit trees to end dormancy and successfully flower and produce fruit (Samish, 1954; Saure, 1985; Erez, 1987). Under warm winter climatic conditions a series of anomalies occur (Saure, 1985), which include delayed, protracted and poor foliage development and bloom, which can lead to uneven fruit development and ripening (Saure, 1985; Erez, 1987; Erez, 2000). Abnormal flowers and poor fruit set have also been reported (Erez, 1987; Jackson, 2000; Petri and Leite, 2004).

Interest in the artificial control of bud break of deciduous fruit trees is closely related to commercial attempts to grow these species in areas where the chilling requirement for dormancy release is not satisfied (Erez, 1987). Only part of the cold requirement can be substituted by other means, e.g. chemicals (Faust *et al.*, 1997). Several chemical compounds have been used to break dormancy, such as mineral oil, potassium nitrate, 6-dinitro-*o*-cresol (DNOC), hydrogen cyanamide (H₂CN₂; HC), thiourea, and some growth regulators (Erez and Zur, 1981; Saure, 1985; Erez, 1987; Krisanapook *et al.*, 1990; Erez, 1995; Jackson and Bepete, 1995; Krisanapook *et al.*, 1995; Erez, 2000).

A rapid rise in xylem cytokinins depicts the completion of endo-dormancy in apple (Tromp and Ovaa, 1990). Chemicals commonly used to partly replace chilling increased the xylem concentration of cytokinins (Cutting *et al.*, 1991). Cytokinin analogs, especially thidiazuron (TDZ), have been used to overcome dormancy (Steffens and Stutte, 1989; Wang *et al.*, 1991). TDZ showed the capacity to release lateral buds from dormancy (Wang *et al.*, 1986). Some chemicals are able to trigger growth in late autumn and again when about two-thirds to three-quarters of the chilling requirement has been satisfied (Erez, 1987; Steffens and Stutte, 1989). In 'Springbrite' nectarine it was reported that success was achieved after only 50% of the chilling requirement was fulfilled using any of the following treatments: a combinations of GA₃, potassium nitrate and alkcolated amine (Armobreak®), GA₃ and fatty acid esters (Waiken®), and hydrogen cyanamide (Dormex®) (George *et al.*, 2002).

The chemical treatments may have variable effects on fruit set, in part because of variability in response to the type of product. Reproductive buds are more sensitive to most of the dormancy

breaking chemicals, and this sensitivity is manifested in flower bud phytotoxicity and loss of flowers (Erez, 2000).

HC became the more used rest-breaking treatment in apples due to its effectiveness in dormancy release, though variable effects on yield, fruit quality, fruit set and blooming period have been observed (Erez, 1987; Jackson and Bepete, 1995; Erez, 2000). In Egypt, Dormex[®] 3% (HC 0.49% v/v) significantly reduced fruit set on 'Dorsett Golden' compared to the untreated control (El-Kassas *et al.*, 1996). In 'Golden Delicious' apple, HC at 0.49% and 0.98% reduced set density and yield, which resulted in an increase in yield the following year, regardless of the oil concentration from 0 to 4% (Paper 1). On the other hand North (1989) found that HC at 2.5% increased fruit set significantly in 'Golden Delicious' apples.

When HC at 1.5 % was evaluated on fully chilled 'Fuji' apple, full bloom was advanced by more than one week and the flowering period from pink bud to full bloom compressed; it reduced fruit set in the first year but not the second (Bound and Jones, 2004). Under insufficient winter chilling conditions the blossom synchronization of different cultivars has been reported in response to HC (Jackson and Bepete, 1995). Our research, carried out over a period of three years (2001–2003) on 'Golden Delicious', 'Royal Gala' apples, showed that while DNOC-oil, HC and TDZ-oil treatments enhanced vegetative budburst compared to the control, reproductive budburst was not always significantly influenced (Paper 2).

In South Africa, most apple producing areas receive insufficient chilling to break dormancy, and the annual application of a chemical rest breaking (RB) treatment is standard practice (Strydom and Honeyborne, 1971). DNOC-oil was the most widely used RB treatment but has recently been replaced mainly by mixtures of HC and oil, which has shown to break dormancy with varying results on fruit set and yield (North, 1989; North, 1992; North, 1993; Paper 1). Detrimental effects on fruit set and yield may be due to increased vegetative growth that increases competition (Erez *et al.*, 2000), or to a phytotoxic effect on flower buds (Nee and Fuchigami, 1992; George and Nissen, 1993).

The objective of this study was to evaluate the effect of DNOC-oil, HC and TDZ in combination with oil on fruit set, yield, and return bloom under marginal winter chilling conditions.

Materials and Methods

Plant material and orchard conditions

The research was conducted on different strains of ‘Golden Delicious’ and ‘Royal Gala’ apples over 3 seasons, from 2001 to 2003, in the Elgin area (34°S, 300 m), Western Cape, South Africa. Six separate trials were conducted, one per cultivar per year. In the first season (2001–2002), trials were conducted to evaluate the effect of HC-oil in comparison to DNOC-oil (the previous standard treatment used in South Africa). In the following two seasons HC-oil (at the same rates as in 2001) was compared to TDZ-oil. The selected trees were trained to a central leader system and were of normal vigour, uniform, and regular bearing. All the experimental sites were orchards under standard commercial cultivation practices. According to Hauage and Cummins (1991), ‘Gala’ apple trees require 1000 Utah model chill units (CU) (Richardson *et al.*, 1974), while according to Erez (2000) ‘Golden Delicious’ apple trees require 1200 CU.

2001–2002: Hydrogen cyanamide-oil and DNOC-oil: For the period May to Aug the area received ca. 820 Utah model chill units (CU; Richardson *et al.*, 1974). Trees were five-years old on M793 rootstock. ‘Golden Delicious’ trees were planted at a spacing of 4.5 x 1.5 m and ‘Royal Gala’ at 4 x 2.5 m. The cross pollinator for both cultivars was ‘Hillieri’ (*Malus hupehensis* (Pamp.) (Rehder)) at 11% of the planting density.

2002–2003: Hydrogen cyanamide-oil and thidiazuron-oil: In 2002, the area received 872 CU. Eight-year-old ‘Golden Delicious’ apple trees on M793 rootstock planted in 1994 at 4 x 1.25 m spacing were chosen. ‘Royal Gala’ apple trees on M793 were planted in 1993 at 4 x 1.5 m. The cross pollinator was ‘Granny Smith’ at 11% of the planting density.

2003–2004: Hydrogen cyanamide-oil and thidiazuron-oil: In 2003, the area received 753 CU. The trials were performed in one orchard, planted in 1998 at 1.5 m x 4.5 m spacing alternating between 2 rows of ‘Golden Delicious’ and 2 rows of ‘Royal Gala’ apple trees on M793 rootstock.

Trial layout and treatments

The experimental layout used in all trials was a randomised complete block design. The 2001 trials consisted of four treatments and six blocks, with single tree plots. Treatments were: HC (Dormex[®], HC 520 g·L⁻¹, 49% v/v) at two rates, 0.245 % and 0.49% for ‘Royal Gala’ and 0.49 % and 0.98% for ‘Golden Delicious’, in combination with oil (Budbreak[®]; mineral oil 863.3 g·L⁻¹) at 4%; DNOC-

oil (DNOC Winter Oil[®], DNOC 3% v/v + mineral oil 72% v/v) at 6%, and one unsprayed control. The 2002 trials were designed with five treatments and ten replication for ‘Golden Delicious’, eight replications for ‘Royal Gala’, and single tree plots. Treatments consisted of HC at the same two concentrations used the previous year in combination with oil at 4% for both cultivars; TDZ-oil (Lift[®], TDZ 3 g·L⁻¹, oil + adjuvants) at two concentrations 3% and 5% for ‘Royal Gala’ and 4% and 6% for ‘Golden ‘Delicious’, and one unsprayed control for each cultivar. In 2003, the same treatments were replicated as for 2002, but with six replications per treatment.

Trees were sprayed to run-off using a handgun. ‘Golden Delicious’ treatments were applied on 26 Sept 2001 (first signs of bud swell; 955 CU), 15 Sept 2003 (70% of the chilling requirement), and 7 Sept 2002 (75% of the chilling requirement, 1200 Utah CU). ‘Royal Gala’ was sprayed on 20 Sept 2001 (first signs of bud swell, 938 Utah CU), 2 Sept 2002 (75% of the chilling requirement, 1000 CU) and 15 Sept 2003 (70% of the chilling requirement).

The spring temperatures were warm, with 5970, 6950, 6330 growing degree hours (GDH, Richardson *et al.*, 1975) accumulated in September 2001, 2002 and 2003, respectively. At the spraying time 5027, 1413 and 2961 GDH had accumulated (from 1 Sept) for ‘Golden Delicious’, and 3718, 441, 2961 GDH for ‘Royal Gala’, in 2001, 2002 and 2003, respectively.

Data recorded

Before budburst two branches per tree, from the lower and upper canopy positions and both with similar orientation and vigour, were randomly selected to assess fruit set. Branch lengths varied roughly from ca. 80 to 120 cm. Fruit set was determined one week after petal drop and again after the “November drop”.

The following data were recorded: number of reproductive clusters at balloon stage, number of fruit per branch, number of fruit per cluster, type of fruit according to the type of flower from which each fruit originated (terminal or lateral) per cluster, total fruit set (fruits/100 reproductive clusters), yield (mass in kilograms and number of fruits), and fruit quality.

Fruit were harvest at commercial harvest maturity. In the first season the tree was divided in three sections in terms of height (upper, middle and lower) to determine fruit distribution within the tree. In the following two years, the trees were harvested as one unit. In ‘Royal Gala’, four partial pickings were completed in the first and second years, and only three in the third year. ‘Golden Delicious’ trees were harvested in one pick.

Fruit quality was assessed in a sample of 25 fruit per tree at the time of commercial harvest. In the first season, this sample was randomly chosen from the tree and in the next two years a sample of 25 fruits was taken from one representative scaffold branch per tree. The fruit quality variables that were evaluated were fruit size (mass, length and diameter), ground colour (chart A.28 Capespan (Capespan Pty, Cape Town, South Africa) from 1 (green) to 9 (yellow), foreground colour (chart A.42 Capespan), from 1 to 12 (1 full red), stem-end russeting (chart A.43 and A.40 Capespan) from 1 to 12 (most severe), retiform russeting (chart A.37, Capespan) from 1 to 11 (most severe); and fruit maturity, as firmness (kg), total soluble solids ($^{\circ}$ Brix) and starch index (1 to 10). Yield efficiency ($\text{kg}\cdot\text{cm}^{-2}$) and fruit density ($\text{fruits}\cdot\text{cm}^{-2}$) were calculated from the total yield per tree and trunk cross sectional area (TCSA), measured ± 25 cm above the soil surface.

Additionally, in the first two seasons of the study the vegetative growth and spur characteristics were evaluated. Two two-year-old branches per tree were randomly selected from the mid peripheral section of the tree. All branches had similar orientation within the canopy. Percentages of budburst, shoot length, number of leaves and leaf area were recorded. Shoot density was expressed as the number of shoots per centimetre of branch length.

Data analysis

The data were subjected to analysis of variance using the General Linear Models (GLM) procedure of Statistical Analysis System program (SAS Institute Cary, N.C.). Means separation was performed when $p \leq 0.1$, using the LSD rank test at the 5% level.

Results

'Golden Delicious'

2001-2002. Hydrogen cyanamide and DNOC-oil: Fruit set, as the number of fruit per hundred clusters, was reduced by HC 0.98% + oil 4%, in comparison to the DNOC-oil and HC 0.49% + oil 4% treatment, but not in comparison to the control (Table 1). Set intensity (number of fruitlets per cluster) was not significantly affected (Figure 1).

The average yield per tree and yield efficiency did not differ significantly (Table 1). Fruit density was reduced by HC 0.98% + oil 4% in comparison to DNOC-oil, but not in comparison to HC 0.49% + oil 4% and the control (Table 1). Increased fruit density was observed following DNOC-oil treatment compared to the control. There was no effect of treatments on fruit distribution in the tree canopy (Table 1). However, the average fruit mass in the upper part of the tree was reduced by

the DNOC-oil and HC 0.49% + oil 4%. The average fruit mass on the tree was reduced by the DNOC-oil treatment but not significantly compared to the HC 0.49% + oil 4% treatment (Table 1).

The final budburst evaluated as a percentage of burst buds on two-year-old shoots was similar for all treatments (Table 2). However, when this variable was analysed as the number of growing buds per centimetre of shoot it was found that the RB treatments resulted in a higher growing bud density with DNOC-oil and HC 0.98% + oil 4% significantly higher than the control (Table 2). In terms of the type of shoot according to length, shoots <10 mm long were abundant following DNOC-oil and HC 0.98% + oil 4% treatments, while HC 0.49% + oil 4% did not differ from the control (Table 2) in this regard. In general, the proportion of longer shoots (> 10 mm) and long spurs (> 5-10 mm) were similar in the case of all treatments, whereas the proportion of short spurs (\leq 5 mm) was higher following DNOC-oil treatment than in the control ($p=0.0760$), but not different from the other treatments (Table 2). The number of leaves on short spurs was increased by all RB treatments ($p=0.0811$) (Table 2). Fruit quality was generally unaffected by the treatments (data not shown).

2002-2003. Hydrogen cyanamide and thidiazuron: The HC 0.98 % + oil 4% treatment reduced the fruit set (No. of number of fruits per 100 clusters) in comparison to the control and TDZ-oil at 6%, and HC 0.49 % + oil 4% reduced fruit set compared to TDZ-oil 6% (Table 3). There were no significant differences in fruitlet abscission evaluated after “November drop” (Table 3). However, hand thinning requirements were significantly higher with TDZ-oil at 6% than for other RB treatments except the control (Table 3). The fruitlets that were removed following the HC + oil treatments were larger than in the control. TDZ-oil treatments generally increased the number of fruit per cluster in comparison to HC 0.98% + oil 4%, where about 50% of the clusters had one fruitlet (Figure 2).

TDZ-oil at 6% increased yield as kg per tree compared to HC + oil and control treatments, while TDZ-oil 4% increased yield over the control. However, only HC 0.98% + oil 4% and TDZ-oil 6% gave a higher yield efficiency than the control (Table 4). There was no effect of the RB treatments on fruit size and shape (Table 4).

All the RB treatments increased the percentage of burst buds on two-year-old shoots (Table 5). The TDZ-oil 6% gave the highest bud burst (100% bud burst), while TDZ-oil 4% was similar to HC 0.98% + oil 4% and higher than HC 0.49% + oil 4%. The HC + oil treatments did not differ significantly (Table 5). All the RB treatments increased the growing buds density (number of burst buds per centimetre shoot length) (Table 5). The HC 0.98% + oil 4% and both TDZ-oil treatments

resulted in a similar total density of growing buds. RB treatments mainly increased the number of short spurs (< 5 mm) (Table 5). The TDZ-oil 4% gave a higher density of short spurs than the HC 0.49% + oil 4% and the control while HC 0.98% + oil 4% and TDZ-oil 6% also increased the short spur density compared to the control (Table 5). TDZ-oil at 6% increased the density of shoots 5-10 mm long compared to the control and TDZ-oil 4% ($p=0.0903$). The density of longer shoots (> 10 mm) density was not affected by the treatments (Table 5).

The spur quality, in terms of number of leaves and leaf area, was influenced by the treatments. RB treatments, except for HC 0.98% + oil 4%, gave a higher number of leaves on short spurs compared to the control, but leaf area was not increased. Long spurs and long shoots were similar for all the treatments in terms of the number of leaves. However, HC 0.98% + oil 4% and 6% TDZ-oil reduced the leaf area of long spurs (5–10 mm) in comparison to the control and HC 0.49% + oil 4% (Table 5). Shoots 10-20 mm long had similar leaf area in all the treatments (data not shown).

A number of buds sprouted at the base of shoots in the scars left by the previous seasons bud scales. The percentage of these burst buds in the “ring” was significantly higher following both TDZ-oil treatments, with about 0.2 burst buds per millimetre of shoot-ring diameter (Table 5). The number of leaves on these shoots was very low (about 1-3 per shoot) (Table 5).

The return bloom the following spring, expressed as percentage of reproductive buds of the total growing buds, was higher with HC 0.49% + oil 4% treatment in comparison to the control and TDZ-oil 4% (Table 5), whereas the density of inflorescences (inflorescences per square centimetre branch cross sectional area) was higher following all the RB treatments. HC 0.98% + oil 4% increased the density of inflorescences compared to the other RB treatments (Table 5).

In terms of fruit quality, TDZ-oil treatments increased the presence of malformed calyx cavities, with 6% TDZ-oil more so than 4% TDZ-oil (Figure 3). The treatments did not affect the incidence of stem-end russet, but HC 0.49% + oil 4% reduced the percentage of non exportable fruit due to stem-end russet (level >8) in comparison to the control (Figure 3).

2003–2004. Hydrogen cyanamide and thidiazuron: Fruit set evaluated as the number of fruit per square centimetre branch cross sectional area was generally increased by the RB treatments, but the increase was only significant following HC 0.49% + oil 4% and 4% TDZ-oil compared to the control ($p=0.0799$) (Table 7). While the number of fruit per hundred clusters was reduced by HC 0.98% + oil 4% ($p=0.0968$), this was mainly in the lower canopy section (Table 6). During this

year, crop load was also reduced by hand thinning. Although the RB treatments generally increased the number of fruit that needed to be removed by hand, only the TDZ-oil 4% differed significantly from the control (Table 6). There was no difference in the proportion of fruitlets removed from the upper or lower canopy (data not shown). The average of hand thinned fruitlet mass in the upper and lower tree section did not differ from the control (Table 6). However, in the upper section the hand thinned fruitlet mass was higher following HC 0.49% + oil 4% compared to TDZ-oil 4% ($p=0.0313$), while in the lower section it was higher for both HC + oil treatments compared to TDZ-oil 4% (Table 6).

Yield and yield efficiency was not influenced by the treatments (Table 7). In terms of fruit size and shape, there was no effect of the RB treatments on the variables measured (Table 7). The return bloom was not significantly affected by the RB treatments (Table 7).

Fruit quality was not affected by the RB treatments in terms of stem-end and reiform russet incidence (data not shown). However, 6% TDZ-oil treatment increased the presence of malformed calyx cavities compared to the other treatments ($p=0.002$) (Figure 7).

'Royal Gala'

2001–2002. Hydrogen cyanamide and DNOC-oil: Fruit set, as the number of fruit per hundred clusters, was reduced by HC 0.49% + oil 4% in comparison to the control ($p=0.0762$), however this treatment did not differ from DNOC-oil and HC 0.245% + oil 4% ($p=0.0762$) (Table 8). In general, the amount of fruit that had to be removed by hand was reduced by all the RB treatments, although HC 0.245% + oil 4% did not differ from the control (Table 8). There was no effect on the hand thinning intensity according to tree section. The average mass of fruitlets removed from the middle canopy section was increased by DNOC-oil 6% and by HC 0.245% + oil 4% compared to the control ($p=0.0881$), but not influenced in the upper and lower canopy sections (Table 8). HC 0.49% + oil 4% increased the set of lateral flowers ($p=0.0801$) compared to DNOC-oil 6% ($p=0.0801$) (Figure 4). The fruit density per cluster was not significantly affected, but it seems that HC 0.49% + oil 4% may have reduced the proportion of clusters with three and four fruits (Figure 4).

Average yield in terms of kilograms per tree was increased ($p=0.0656$) by HC 0.245% + oil 4% treatment compared to the control and HC 0.49% + oil 4% (Table 9). Yield efficiency and fruit density were higher than all other treatments following the HC 0.245% + oil 4% treatment (Table 9). The fruit distribution in the canopy was influenced by the RB treatments; the proportion of the crop from the middle and upper parts of the tree was generally increased to 50%, while in the

control it was 35% (Table 9). Four picks were done according to colour with the best coloured fruit (> 50% red foreground) harvested first. There were no differences in terms of percentage of fruits per pick (Table 9). Fruit mass from the middle part of the tree was higher ($p=0.0778$) following the DNOC-oil 6% and 0.245% HC + 4% HC treatments ($p=0.0778$) (Table 10).

Regarding vegetative budburst on two-year-old shoots, the RB treatments did not significantly affect the percentage of burst buds, but when expressed as number of buds per centimetre of shoot, the density of growing buds was higher following the RB treatments (Table 11). This difference was mainly due to a higher percentage of spurs (shoots < 10 mm). HC 0.245% + oil 4% decreased the density of longer shoots (>10 mm) compared to other treatments. The number of leaves on short spurs (≤ 5 mm) was reduced by 0.49% HC + 4 % oil compared to control and DNOC-oil 6% (Table 11).

2002–2003. Hydrogen cyanamide and thidiazuron: Fruit set and intensity of fruitlet abscission were not significantly affected by the RB treatments (Table 12). However, the number of fruitlets per cluster was generally modified by the RB treatments (Figure 5). The proportion of clusters with two fruits was higher following the RB treatments. The intensity of hand thinning required was reduced by HC 0.49% + oil 4% compared to the control and TDZ-oil treatments (Table 12). In general, fruitlets that had to be hand thinned were smaller following TDZ-oil treatments (Table 13).

The average yield in terms of kilograms per tree was reduced following 5% TDZ-oil in comparison to the control ($p=0.0783$), whereas yield efficiency was reduced by all the RB treatments except for HC 0.245% + oil 4% (Table 13). There was no effect on fruit mass and shape (Table 14).

Vegetative bud burst on two-year-old shoots was significantly higher following TDZ-oil treatments (Table 14). However, this difference was not significant when the growing buds were analysed as the number of growing buds per centimetre shoot length (Table 14). The short spur (<5 mm) density was increased by 5% TDZ-oil compared to the control and HC 0.49% + oil 4% ($p=0.0779$), while the density of long shoots (>10 mm) was increased by TDZ-oil at both rates compared to the control ($p=0.0817$). No effect was observed on the proportion of long spurs (5-10 mm) (Table 14). In terms of shoot quality, there was no difference in the number of leaves and leaf area of short spurs (<5 mm). 0.245% HC + oil increased the number of leaves of long spurs (5-10 mm) compared to other RB treatments. 5% TDZ-oil decreased the leaf area on long spurs compared to the control and HC + oil treatments ($p=0.0661$) (Table 14).

As the case of ‘Golden Delicious’, a number of buds sprouted at the base of shoots, in the scars left by the previous season’s bud scales. The percentage of these buds that burst in the “ring” was higher following TDZ-oil treatments compared to the control and HC 0.245% + oil 4%. In terms of bud density, TDZ-oil treatments gave the higher number of burst buds (0.3) per millimetre of shoot-ring diameter compared to other treatments (Table 14). However, the number of leaves on these shoots was not significantly affected (Table 14). All the shoots were very small, with few leaves (1-3).

The return bloom for the following spring expressed as percentage of the total growing buds was reduced by 5% TDZ-oil compared to other treatments (Table 14). The number of inflorescences per centimetre branch circumference was increased by 0.49% + oil compared to other treatments, except for 3% TDZ-oil (Table 14). Treatments did not significantly affect the harvest distribution (Figure 6).

2003–2004. Hydrogen cyanamide and thidiazuron: Fruit set as number of fruits per square centimetre cross sectional area was not influenced by RB the treatments (Table 15). However, 5% TDZ-oil increased the number of fruits per hundred clusters compared to other treatments except for 3% TDZ-oil (Table 16). The number of fruit that needed to be removed by hand was increased by both rates of TDZ-oil in comparison to HC 0.49% + oil 4% (Table 16). There was no effect on the proportion of removed fruit according to canopy section (data not shown). The mass of removed fruitlet was not affected by the treatments on the upper part of the tree, but fruitlet mass was less on the lower canopy section following 5% TDZ-oil compared to the control and HC + oil treatments (Table 15).

TDZ-oil at 3% increased yield as kg per tree compared to the control, HC 0.245 + oil 4% and TDZ-oil 5% ($p=0.0917$). However, yield efficiency was not significantly increased by the RB treatments (Table 16). Fruit diameter, length and average mass were reduced by the TDZ-oil treatments compared to the control and HC 0.245% + oil 4% (Table 16). However, there was no effect on fruit shape (Table 17). The incidence of defects and fruit colour was unaffected by the treatments (data not shown). The HC 0.49% + oil 4% increased return bloom the following season compared to the control and TDZ-oil 5% (Table 17).

Discussion

In general, HC + oil reduced fruit set in 'Golden Delicious', but this was dependent on the rate of application and the season. In the first year, HC at the higher concentration + oil resulted in a lower fruit set than DNOC-oil treatment. This reduction could be due to a decrease in the number of fruits per cluster or, to an increased in clusters with no fruit set or to a loss of flowers. A phytotoxic effect on reproductive buds, especially in the first year of the study when the applications were done late (26 Sep) at first sign of bud swelling, may explain the reduction in fruit setting. A similar effect of HC on fruit set was observed by Finetto (1993). It has been reported that late applications of HC induces phytotoxicity and reduces fruit set (Paper 1). Several authors have reported that later applications and higher HC rates result in a greater response in bud burst, but more phytotoxicity (Samish, 1954; Saure, 1985; Shulman *et al.*, 1986; Erez, 1987; Fallahi *et al.*, 1992 ; Siller-Cepeda *et al.*, 1992 ; Lee, 1994; Erez, 2000; Bound and Jones, 2004)

The time of application appears to be crucial, especially in cases where spring weather is warm. Not all buds on a tree require the same amount of winter chilling. Flower buds have a lower chilling requirement than vegetative buds, and terminal buds have a lower chilling requirement than lateral buds (Samish and Lavee, 1962, cit. Saure, 1985). Among lateral buds, there may be noticeable differences relative to position on the shoot. Extended chilling, however, does tend to normalise these differences (Cook *et al.*, 1998), and also warm temperature in spring may compensate for lack of chilling. With a lack of chilling, happens the heat requirement for budburst increases (Erez, 2000). However, budburst is protracted and foliation is delayed. Under conditions of insufficient winter chilling, conditions high spring temperature may accelerate the development of those buds that are more advanced and thereby accentuating the phytotoxic effect of RB treatments and causing protracted and delayed bud burst.

As described by Erez (2000), flower buds are more sensitive than other tree organs to most of the dormancy breaking chemicals, and this sensitivity manifests in flower bud phytotoxicity and loss of flowers. The reduced fruit set resulted in a reduced hand thinning requirement. This situation should be taken into account when deciding on chemical thinning practices since HC can compress the flowering period (see Paper 2) and induce reduced fruit set.

TDZ may also result in a reduction in fruit set. In 'Golden Delicious', when TDZ and HC were applied in a year with more chilling accumulation compared to the next year trial (906 Richardson CU vs 832 CU), bud burst was increased more following TDZ-oil than with HC plus oil treatments

(see Paper 2). It appeared that late applications of TDZ induces increased bud burst, perhaps due to a more advanced stage of bud differentiation at the time of application, resulting in a stronger effect of these cytokinin-like compounds on cell division. High concentrations of TDZ applied to ‘Anna’ apple trees induced a rapid increase in gibberellins and cytokinin levels (Bondok *et al.*, 1995). On the other hand, when the effect of TDZ-oil was evaluated at different stages during the same season, late application reduced fruit set (see Paper 4).

Although fruit set was reduced in some years by 0.49% HC and 0.98% HC + oil in ‘Royal Gala’ and ‘Golden Delicious’, respectively, yield was not reduced. Since the hand thinning criteria were the same (reducing fruit number per cluster to two and removing small fruitlets), fewer fruit needed to be removed by hand, and yield was even higher in some cases.

The rest-breaking treatments increased the final budburst on two-year-old shoots in ‘Golden Delicious’ and ‘Royal Gala’, resulting mainly in an increase of short spurs (≤ 5 mm long), and number of leaves on this type of shoot. This may improve the bud quality for the following season, although the leaf area per shoot was not significantly increased. The effective leaf area per spur is an important factor in flower initiation and differentiation (Monselise and Goldschmidt, 1982). Differences in flower bud quality as affected by competition within flower clusters and vigour of the fruiting wood also determine fruit size (Volz *et al.*, 1994). However, excessive vegetative growth delays flower induction and induce competition (Forshey and Elfving, 1989). Total bud burst in 2003/2004 was strongly increased by the higher rates of TDZ-oil in both cultivars. Therefore, an increased reproductive potential for the following season could be expected.

TDZ-oil at 5% applied in 2002/2003 reduced the return bloom in ‘Royal Gala’ when expressed as reproductive buds as a percentage of total buds, probably due to an increased vegetative growth which influenced negatively on flower bud induction. Flower induction may be delayed if the trees are bearing a heavy crop or are highly vigorous (Forshey and Elfving, 1989), and delayed flower induction may affect negatively reproductive bud quality. It has been proved that in apples an increased vegetative growth is negatively correlated (-0,74 to -0,95) to flower formation (Jones *et al.*, 1989). TDZ-oil at higher rates in both varieties stimulated budburst, as can be seen in the bursting of buds in the “ring” scales and at the base of some lateral buds, resulting in growth with abnormal small leaves. Earlier, budburst was reported on in Paper 2.

The detrimental effect of TDZ-oil appears to be the malformation of the calyx cavity in ‘Golden Delicious’ (Figure 7). This was investigated further and will be reported on in Paper 4.

Conclusion

In conclusion, HC plus oil is an effective treatment to break dormancy in apple trees in warm winter areas. High rates, namely 0.49% for 'Gala' and 0.98% for 'Golden Delicious' in a mix with oil at 4%, could however reduce fruit set. A combination of TDZ plus oil was effective in increasing budburst. However, the effect on fruit set and yield was variable. Yield could possibly be increased by TDZ-oil applications. Return bloom the following spring was reduced, when applied at 5% in 'Royal Gala'. Malformation of the calyx cavity appears to be the main problem of this cytokinin-like compound in 'Golden Delicious' apples when applied as a rest breaking treatment. Hence, the time of application is crucial and an optimal time has to be established according to some quantitative or qualitative parameters.

Literature Cited

- Bondok, M.A., Abdel-Hamid, N. and El-Wakeel, H.F., 1995. Bud break, fruit maturity and yield of "Anna" apple as influenced by plant bioregulator "Thidiazuron". *Annals of Agricultural Science (Cairo)* 40: 343-358.
- Bound, S.A. and Jones, K.M., 2004. Hydrogen cyanamide impacts on flowering, crop load, and fruit quality of red 'Fuji' apple (*Malus domestica*). *New Zealand Journal of Crop and Horticultural Science* 32: 227-234.
- Cook, N.C., Rabe E, Keulemans, J. and Jacobs, G., 1998. The expression of acrotony in deciduous fruit trees: a study of the apple rootstock M9. *Journal of the American Society for Horticultural Science* 123: 30-34.
- Cutting, J.G.M., Strydom, D.K., Jacobs, G., Bellstedt, D.U., Merwe, K.J.v.d. and Weile, E.W., 1991. Changes in xylem constituents in response to rest-breaking agents applied to apple before budbreak. *Journal of the American Society for Horticultural Science* 116: 680-683.
- El-Kassas, S.E., El-Sese, M.A., El-Salhy, A.M. and El-Wasfy, M.M., 1996. Physiological studies on flowering, fruit setting and bearing habits of some apple cultivars under Assiut environment. *Assiut Journal of Agricultural Sciences* 27: 3-21(abstract).
- Erez, A., 1987. Chemical control of budbreak. *HortScience* 22: 1240-1243.
- Erez, A., 1995. Means to compensate for insufficient chilling to improve bloom and leafing. *Acta Horticulturae* 395: 81-95.
- Erez, A. 2000. Bud dormancy; phenomenon, problems and solutions in the tropics and subtropic. In: Erez, A. (Ed.), *Temperate fruit crops in warm climate*, pp. 17-48. Bet-Dagan: Kluwer Academic Publishers. 48 pp.

- Erez, A., Yablowitz, Z. and Korcinski, R., 2000. Temperature and chemical effects on competing sinks in peach bud break. *Acta Horticulturae* 514: 51-58.
- Erez, A. and Zur, A., 1981. Breaking the rest of apple buds by narrow-distillation-range oil and dinitro-o-cresol. *Scientia Horticulturae* 14: 47-54.
- Fallahi, E., Simons, B.R., Fellman, J.K. and Colt, W.M., 1992. Use of hydrogen cyanamide for apple and plum thinning. *Plant Growth Regulation* 11: 435-439.
- Faust, M., Erez, A., Rowland, L.J., Wang, S.Y. and Norman, H.A., 1997. Bud dormancy in perennial fruit trees: physiological basis for dormancy induction, maintenance, and release. *HortScience* 32: 623-629.
- Finetto, G.A., 1993. The effect of hydrogen cyanamide on breaking endo-dormancy of mid-chilling apple cultivars in Yemen during two years. *Acta Horticulturae* 329: 268-270.
- Forshey, C.G. and Elfving, D.C., 1989. The relationship between vegetative growth and fruiting in apple trees. *Horticultural Reviews* 11: 229-287.
- George, A.P., Broadley, R.H., Nissen, R.J. and Ward, G., 2002. Effects of new rest-breaking chemicals on flowering, shoot production and yield of subtropical tree crops. *Acta Horticulturae* 575: 835-840.
- George, A.P. and Nissen, R.J., 1993. Effect on growth regulants on defoliation, flowering, and fruit maturity of the low chilling peach cultivar Flordaprince in subtropical Australia. *Australian Journal of Experimental Agriculture* 33: 787-795.
- Hauagge, R. and Cummins, J.N., 1991. Phenotypic variation of length of bud dormancy in apple cultivars and related *Malus* species. *Journal of the American Society for Horticultural Science* 116: 100-106.
- Jackson, J.E. 2000. Apple production at low latitudes. In: Erez, A. (Ed.), *Temperate fruit crops in warm climate*, pp. 305-342. Kluwer Academic Publisher. 342 pp.
- Jackson, J.E. and Bepete, M., 1995. The effect of hydrogen cyanamide (Dormex) on flowering and cropping of different apple cultivars under tropical conditions of sub-optimal winter chilling. *Scientia Horticulturae* 60: 293-304.
- Krisanapook, K., Ogata, R. and Subhadrabandhu, S., 1990. Study on some cultural practices to induce lateral bud emergence in apple trees grown under warm conditions. *Acta Horticulturae* 279: 275-282.
- Krisanapook, K., Subhadrabandhu, S. and Ogata, R., 1995. Induction of budbreak in apple trees that received insufficient chilling by hydrogen cyanamide. *Kasetsart Journal, Natural Sciences* 29: 239-245.
- Lang, G.A., Early, J.D., Arroyave, N.J., Darnell, R.L., Martin, G.C. and Stutte, G.W., 1985. Dormancy: towards a reduced, universal terminology. *HortScience* 20: 809-811.
- Lee, R.R.. 1994. Interrelationships between flowering habit, fruit characteristics, hydrogen cyanamide applications, and xylem cytokinin levels in 'Rome Beauty' apples (*Malus domestica* Bork.). University of Idaho.

- Monselise, S.P. and Goldschmidt, E.E., 1982. Alternate bearing in fruit trees. *Horticultural Reviews* 4: 128-173.
- Nee, C.C. and Fuchigami, L.H., 1992. Overcoming rest at different growth stages with hydrogen cyanamide. *Scientia Horticulturae* 50: 107-113.
- North, M., 1989. Effect of cyanamide and DNOC/oil on budbreak, yield and fruit size of Golden Delicious apples. *South African Journal of Plant and Soil* 6: 176-178.
- North, M., 1992. Alternative rest-breaking agent for apples. *South African Journal of Plant and Soil* 9: 39-40.
- North, M., 1993. Effect of application date on the rest-breaking action of cyanamide on 'Golden Delicious' apples. *Deciduous Fruit Grower* 43: 470-472.
- Petri, J.L. and Leite, G.B., 2004. Consequences of insufficient winter chilling on apple tree bud-break. *Acta Horticulturae* 662: 53-60.
- Richardson, E.A., Seeley, S.D. and Walker, D.R., 1974. A model for estimating the completion of rest for 'Redhaven' and 'Elberta' peach trees. *HortScience* 9: 331-332.
- Richardson, E.A., Seeley, S.D., Walker, D.R., Anderson, J.L. and Ashcroft, G.L., 1975. Phenoclimatology of spring peach bud development. *HortScience* 10: 236-237.
- Samish, R.M., 1954. Dormancy in woody plants. *Annual Review of Plant Physiology* 5: 183-204.
- Saure, M.C., 1985. Dormancy release in deciduous fruit trees. *Horticultural Reviews* 7: 239-300.
- Shulman, Y., Nir, G. and Lavee, S., 1986. Oxidative processes in bud dormancy and the use of hydrogen cyanamide in breaking dormancy. *Acta Horticulturae* 179: 141-148.
- Siller-Cepeda, J.H., Fuchigami, L.H. and Chen, T.H.H., 1992. Hydrogen cyanamide-induced budbreak and phytotoxicity in 'Redhaven' peach buds. *HortScience* 27: 874-876.
- Steffens, G.L. and Stutte, G.W., 1989. Thidiazuron substitution for chilling requirement in three apple cultivars. *Journal of Plant Growth Regulation* 8: 301-307.
- Strydom, D.K. and Honeyborne, G.E., 1971. Delayed foliation of pome and stone fruits. *Deciduous Fruit Grower* 21: 126-129.
- Tromp, J. and Ova, J.C., 1990. Seasonal changes in cytokinin composition of xylem sap of apple. *Journal of Plant Physiology* 136: 606-610.
- Volz, R.K., Ferguson, I.B., Hewett, E.W. and Woolley, D.J., 1994. Wood age and leaf area influence fruit size and mineral composition of apple fruit. *Journal of Horticultural Science* 69: 385-395.
- Wang, S.Y., Jiao, H.J. and Faust, M., 1991. Changes in metabolic enzyme activities during thidiazuron-induced lateral budbreak of apple. *HortScience* 26: 171-173.
- Wang, S.Y., Steffens G.L. and Faust, M., 1986. Breaking bud dormancy in apple with a plant bioregulator, thidiazuron. *Phytochemistry* 25: 311-317.

Table 1. Effect of hydrogen cyanamide (HC) with oil and DNOC-oil on fruit set, yield, yield distribution and fruit mass according to tree section on 'Golden Delicious' trees in the Elgin area, South Africa (season 2001/2002).

Treatment	Fruit set (fruits/100 clusters)	Average yield per tree (kg)	Yield efficiency (kg cm ⁻² TCSA) ^z	Fruit density (No. cm ⁻² TCSA)	Yield distribution on the tree			Fruit mass according to tree section				
					Top	Middle	Bottom	Top	Middle	Bottom	Total tree	
Control	46.3 ab ^y	25.6 n.s.	(28.5) ^x	0.171 n.s.	1.410 b	28.2 n.s.	43.7 n.s.	28.1 n.s.	107.5 a	107.0 n.s.	150.7 n.s.	117.4 a
DNOC-oil 6%	58.2 a	44.5	(49.5)	0.285	2.938 a	24.4	45.7	29.9	92.2 b	96.2	94.4	94.6 b
HC 0.49% + oil 4%	68.7 a	35.9	(39.9)	0.217	2.188 ab	26.3	43.2	30.6	91.6 b	104.4	107.8	101.5 ab
HC 0.98% + oil 4%	21.8 b	23.1	(25.6)	0.144	1.225 b	30.2	34.0	35.8	113.2 a	107.8	125.6	117.5 a
Pr>F	0.0282	0.1076		0.1781	0.0423	0.8940	0.5087	0.6378	0.0124	0.3423	0.3507	0.0254

^z TCSA = trunk cross sectional area

^y Means within each column with the same letter are not significantly different at p = 0.05. n.s. = no significant differences

^x Estimated yield in ton·ha⁻¹ given in brackets

Table 2. Effect of hydrogen cyanamide (HC) with oil and DNOC-oil on vegetative growth and spur quality on two-year-old shoots, cv. 'Golden Delicious' in the Elgin area, South Africa (season 2001/2002).

Treatment	Bud burst (%)	Growing buds density	Shoot density (growth >10 mm)	Spurs density (growth <10 mm)	Shoot type distribution according to length			Number of leaves on spur ≤5 mm
					≤5 mm	5–10 mm	>10 mm	
Control	75.6 n.s. ^z	0.182 b	0.0727 n.s.	0.1090 b	46.4 b	15.0 n.s.	38.5 n.s.	2.8 b
DNOC-oil 6%	88.6	0.263 a	0.0310	0.2323 a	82.4 a	5.7	11.8	3.8 a
HC 0.49% + oil 4%	84.4	0.234 ab	0.0679	0.1665 ab	66.7 ab	5.5	27.9	4.0 a
HC 0.98% + oil 4%	85.5	0.269 a	0.0576	0.2115 a	72.7 ab	6.1	21.2	4.0 a
Pr>F	0.9549	0.047	0.7187	0.0063	0.0760	0.4536	0.1382	0.0811

^z Means within each column with the same letter are not significantly different at p = 0.05. n.s. = no significant differences

^y BL = branch length (cm)

Table 3. Effect of rest breaking treatments on fruit set and hand-thinning requirements of 'Smoothie Golden' apple trees, in the Elgin area, South Africa (season 2002/2003).

Treatment	Fruit set (fruitlets/ 100 clusters)	Fruitlets ^z abscission (No·cm ⁻² TCSA) ^y	Fruitlets hand-thinned (No. cm ⁻² TCSA)	Average fruitlet mass (g)	
				First thinning	Second thinning
Control	166.0 ab ^x	1.672 n.s.	6.17 ab	3.5 b	23.4 b
HC 0.49% + oil 4%	110.2 bc	0.934	4.70 b	4.3 a	27.2 a
HC 0.98% + oil 4%	98.1 c	1.081	4.77 b	4.4 a	26.9 a
TDZ-oil 4%	138.0 abc	1.139	5.43 b	4.1 ab	23.9 b
TDZ-oil 6%	183.8 a	1.769	7.66 a	3.9 ab	23.4 b
Pr>F	0.0041	0.4137	0.0455	0.0965	0.0046

^z Fruits that have dropped^y TCSA = trunk cross sectional area^x Means within each column with the same letter are not significantly different at p = 0.05. n.s. = no significant differences

Table 4. Effect of rest breaking treatments on yield and fruit size of 'Smoothie Golden' apples, in the Elgin area, South Africa (season 2002/2003).

Treatment	Average yield per tree (kg)		Yield efficiency (kg·cm ⁻² TCSA) ^z	Fruit size			
				Diameter (mm)	Length (mm)	Length/ diameter ratio	Average fruit mass (g)
Control	36.1 c ^y	(72.2) ^x	0.421 b	62.5 n.s.	59.6 n.s.	0.998 n.s.	118.1 n.s.
HC 0.49% + oil 4%	42.5 bc	(84.9)	0.468 ab	64.4	60.0	0.931	123.5
HC 0.98% + oil 4%	47.1 bc	(94.2)	0.541 a	62.7	58.9	0.940	117.0
TDZ-oil 4%	51.1 ab	(102.2)	0.508 ab	62.5	59.4	0.952	113.1
TDZ-oil 6%	54.4 a	(108.9)	0.576 a	61.9	58.5	0.945	114.6
Pr>F	0.0080		0.0089	0.2377	0.5900	0.2203	0.3805

^z TCSA = trunk cross sectional area^y Means within each column with the same letter are not significantly different at p= 0.05. n.s. = no significant differences^x Estimated yield in ton·ha⁻¹ given in brackets

Table 5. Effect of rest breaking treatments on vegetative growth and spur quality on two-year-old shoots and return bloom, cv. Smoothie Golden Delicious in the Elgin area, South Africa (season 2002/2003).

Treatment	Burst buds on 2-year-old shoots ^z (%)	Growing bud density according to shoot length (units·cm ⁻¹ BL ^y) ^z				Number of leaves per shoot			Leaf area per shoot (cm ²)	
		Total	<5 mm	5–10 mm	>10mm	<5mm	5–10 mm	>10 mm	<5 mm	5–10 mm
Control	49.9 d ^x	0.158 c	0.087 c	0.040 b	0.031 n.s.	2.1 c	5.0 n.s.	6.5 n.s.	22.6 n.s.	74.7 a
HC 0.49% + oil 4% ^y	81.9 c	0.246 b	0.123 bc	0.070 ab	0.052	2.9 ab	4.5	6.3	26.6	75.4 a
HC 0.98% + oil 4%	91.7 bc	0.300 a	0.160 ab	0.067 ab	0.073	2.4 bc	5.0	6.9	20.5	48.6 b
TDZ-oil 4%	94.5 b	0.301 a	0.196 a	0.055 b	0.050	3.0 a	4.6	6.5	24.5	56.2 ab
TDZ-oil 6%	100.0 a	0.347 a	0.178 ab	0.111 a	0.058	3.0 ab	4.6	6.3	24.4	53.6 b
Pr>F	<0.0001	<0.0001	0.0182	0.0903	0.2921	0.0041	0.6650	0.9915	0.4251	0.0224

(Cont. Table 5)

Treatment	Ring shoots			Return bloom	
	Burst buds in the ring (%)	Density (shoots · mm ⁻¹ RD ^w)	No. of leaves /shoot	(inflorescences · cm ⁻²)	(%) ^v
Control	3.3 b	0.022 b	0.3	4.64 c	36.2 b
HC 0.49% + oil 4% ^y	1.0 b	0.023 b	1.3	7.88 b	45.8 a
HC 0.98% + oil 4%	5.3 b	0.078 b	2.4	12.19 a	43.5 ab
TDZ-oil 4%	16.0 a	0.267 a	2.1	6.46 b	35.3 b
TDZ-oil 6%	12.7 a	0.238 a	2.7	6.12 b	37.9 ab
Pr>F	<0.0001	<0.0001	0.7233	0.0711	0.0865

^z growing buds under the ring

^y BL = branch length (cm)

^x Means within each column with the same letter are not significantly different at p = 0.05.

^w RD = ring diameter (mm)

^v Reproductive buds as percentage of total buds

Table 6. Effect of rest breaking treatments on fruit set and hand thinning requirements on 'Golden Delicious' apple trees, in the Elgin area, South Africa (season 2003/2004).

Treatment	Fruit density (No·cm ⁻² BCSA) ^z	Fruit set (Fruitlets/100 clusters)			Hand thinning requirement			
		Average	Lower branch	Upper branch	No. cm ⁻² TCSA ^z	Average fruitlet mass according to tree section (g)		
						Upper	Lower	
Control	3.63 b ^y	297.1	267.3 a	358.4	4.608 b (194) ^x	9.1 ab	11.4 ab	
HC 0.49% + oil 4%	10.63 a	242.0	246.4 a	260.6	6.975 ab (335)	9.3 ab	13.0 a	
HC 0.98% + oil 4%	6.35 ab	178.5	166.8 b	231.4	4.723 b (210)	12.2 a	13.1 a	
TDZ-oil 4%	9.41 a	259.3	263.5 a	284.9	8.813 a (393)	7.6 b	10.4 b	
TDZ-oil 6%	6.57 ab	246.1	196.6 ab	308.1	6.729 ab (281)	9.3 ab	10.9 ab	
Pr>F	0.0799	0.1444	0.0968	0.3873	0.0028	0.0313	0.0683	

^z BCSA = branch cross sectional area; TCSA = trunk cross sectional area

^y Means within each column with the same letter are not significantly different at p = 0.05.

^x Number of hand thinned fruits per tree given in brackets

Table 7. Effect of rest breaking treatments on yield and fruit size and return bloom of 'Golden Delicious' apples in the Elgin area, South Africa (season 2003/2004).

Treatment	Average yield per tree (kg)	Yield efficiency (kg cm ⁻² TCSA) ^z	Diameter (mm)	Length (mm)	Length/diameter ratio	Average fruit mass (g)	Return bloom ^w (%)
Control	22.8 (33.8) ^y	0.545	66.1	61.5	0.931	133.6	26.5
HC 0.49% + oil 4%	26.1 (38.6)	0.546	65.2	60.7	0.932	128.9	35.9
HC 0.98% + oil 4%	23.3 (34.6)	0.519	66.3	61.4	0.926	134.6	46.5
TDZ-oil 4%	27.7 (41.1)	0.610	63.8	59.3	0.930	121.5	42.5
TDZ-oil 6%	23.9 (35.4)	0.607	64.6	60.2	0.932	124.8	35.3
Pr>F	0.7244	0.7936	0.2935	0.4593	0.9020	0.2524	0.1327

^z TCSA = trunk cross sectional area

^y Estimated yield in ton·ha⁻¹, in brackets

^w Reproductive buds as percentage of total buds

Table 8. Effect of hydrogen cyanamide (HC) with 4% oil and DNOC-oil on fruit set and hand thinning requirements on 'Royal Gala' apple trees in the Elgin area, South Africa (season 2001/2002).

Treatment	Fruit set (Fruits/100 clusters)	Hand thinning		Hand thinning distribution according to tree section (%)			Average fruitlet mass per tree sections (g)					
		Number of fruitlets (No. cm ⁻² TCSA) ^y	Total weight (g cm ⁻² TCSA)	Top	Middle	Bottom	Top	Middle	Bottom	Average		
Control	119.3 a ^z	0.623 a	(59.6) ^x	13.16 a	(1.25) ^x	43.8 n.s.	17.3 n.s.	38.8 n.s.	20.6 n.s.	17.8 b	23.2 n.s.	21.2 n.s.
DNOC-oil 6%	99.6 ab	0.284 b	(31.1)	6.52 b	(0.69)	35.5	31.9	32.5	22.5	24.3 a	21.6	22.9
HC 0.245% + oil 4%	79.5 ab	0.474 ab	(42.1)	10.65 ab	(0.94)	25.4	37.3	37.2	20.4	23.7 a	26.9	22.9
HC 0.49% + oil 4%	62.7 b	0.366 b	(38.6)	7.87 b	(0.84)	37.1	26.9	36.0	21.8	20.4 ab	20.5	21.2
Pr>F	0.0762	0.0133		0.0435		0.6515	0.2396	0.9272	0.9421	0.0881	0.4442	0.8075

^z Means within each column with the same letter are not significantly different at p = 0.05. n.s. = no significant differences

^y TCSA = trunk cross sectional area

^x Number of fruits and total weight per tree in kg, in brackets

Table 9. Effect of hydrogen cyanamide (HC) with 4% oil and DNOC-oil on yield of 'Royal Gala' trees in the Elgin, South Africa (season 2001/2002).

Treatment	Average yield per tree (kg)		Yield efficiency (kg·cm ⁻² TCSA) ^y	Fruit density (No.·cm ⁻² TCSA)	Yield distribution according to tree section (%)			Harvest distribution (%)			
		()			Top	Middle	Bottom	1 st Pick	2 nd Pick	3 rd Pick	4 th Pick
Control	34.2 b ^z	(34.2)	0.357 b	3.36 b	16.1 b	18.3 b	65.6 a	5.9 n.s.	30.5 n.s.	28.0 n.s.	35.6 n.s.
DNOC-oil 6%	35.5 ab	(35.5)	0.324 b	2.77 b	22.4 ab	24.5 ab	53.1 b	3.9	28.5	25.1	42.5
HC 0.245% + oil 4%	39.6 a	(39.6)	0.449 a	4.13 a	18.9 ab	32.0 a	49.0 b	3.1	28.6	21.1	47.2
HC 0.49% + oil 4%	32.1 b	(32.1)	0.308 b	2.74 b	25.2 a	28.9 a	45.9 b	3.7	31.5	24.1	40.6
Pr>F	0.0656		0.0015	0.0030	0.0978	0.0257	0.0092	0.5513	0.6106	0.6350	0.4950

^z Means within each column with the same letter are not significantly different at p = 0.05. n.s. = no significant differences

^y TCSA = Trunk cross sectional area

Table 10. Fruit mass according to tree section on 'Royal Gala' apple trees in the Elgin area, South Africa (season 2001/2002).

Treatment	Fruit mass (g) according to tree section			
	Top	Middle	Bottom	Tree
Control	95.9 n.s. ^z	99.4 b	112.5 n.s.	106.4 n.s.
DNOC-oil 6%	105.7	111.9 a	128.3	117.4
HC 0.245% + oil 4% ^x	105.6	112.5 a	107.8	109.0
HC 0.49% + oil 4%	120.4	108.0 ab	116.0	112.5
Pr>F	0.4020	0.0778	0.4470	0.3864

^z n.s. = no significant differences

Means within each column with the same letter are not significantly different at $p = 0.05$.

Table 11. Effect of hydrogen cyanamide (HC) with 4% oil and DNOC-oil on budburst, vegetative growth and spur quality on two-year-old wood, cv. 'Royal Gala' in the Elgin area, South Africa (season 2001/2002).

Treatment	Percentage budburst (%)	Growing buds density	Shoot density (>10 mm long)	Spur density (<10 mm long)	Shoot type distribution according to length			Number of leaves per spur ≤ 5 mm
					≤ 5 mm	5–10 mm	>10 mm	
					units $\cdot \text{cm}^{-1}$ BL ^y			
					units $\cdot \text{cm}^{-1}$ BL ^y			
Control	73.9 n.s. ^z	0.179 b	0.049 a	0.129 b	69.7 n.s.	7.8 n.s.	22.6 n.s.	3.3 a
DNOC-oil 6%	80.6	0.257 a	0.049 a	0.208 a	63.4	15.0	21.6	3.5 a
HC 0.245% + oil 4% ^x	80.1	0.266 a	0.028 b	0.238 a	70.5	19.2	10.2	3.2 ab
HC 0.49% + oil 4%	84.1	0.270 a	0.049 a	0.221 a	68.9	12.8	18.3	2.3 b
Pr>F	0.5684	0.0024	0.0061	0.0007	0.8391	0.5571	0.5799	0.0587

^z n.s. = no significant differences. Means within each column with the same letter are not significantly different at $p = 0.05$.

^y BL = branch length (cm)

Table 12. Effect of rest breaking treatments on fruit set on 'Royal Gala' apple trees, in the Elgin area, SouthAfrica (season 2002/2003).

Treatment	Fruit set (fruitlets/100 clusters)	Fruitlets abscission (No.·cm ⁻² TCSA) ^z	Fruitlets hand thinned (No.·cm ⁻² TCSA)	Average fruitlet mass (g)	
				First thinning	Second thinning
Control	184.5 n.s. ^y	0.13 n.s.	2.48 ab	6.7 a	16.0 ab
HC 0.245% + oil 4%	157.5	0.09	1.94 bc	6.5 ab	16.5 ab
HC 0.49% + oil 4%	111.8	0.06	1.64 c	7.1 a	17.2 a
TDZ-oil 4%	125.9	0.17	2.66 ab	6.1 bc	15.0 bc
TDZ-oil 6%	152.3	0.11	2.91 a	5.6 c	14.2 c
Pr>F	0.1776	0.1251	0.0419	0.0129	0.0195

^z TCSA = trunk cross sectional area^y Means within each column with the same letter are not significantly different at p = 0.05. n.s. = no significant differences.

Table 13. Effect of rest breaking treatments on yield and fruit size of 'Royal Gala' apple trees (season 2002/2003).

Treatment	Average yield per tree (kg)		Yield efficiency (kg·cm ⁻² TCSA) ^z	Diameter (mm)	Length (mm)	Length/ diameter ratio	Average fruit mass (g)
Control	54.1 a ^x	(90.1) ^y	0.439 a	58.4 n.s.	51.1 n.s.	0.874 n.s.	90.4 n.s.
HC 0.245% + oil 4%	49.7 ab	(82.8)	0.394 ab	58.8	51.8	0.880	92.4
HC 0.49% + oil 4%	44.7 ab	(74.5)	0.356 b	58.6	51.7	0.882	92.1
TDZ-oil 3%	45.6 ab	(75.9)	0.367 b	58.6	51.5	0.878	92.9
TDZ-oil 5%	39.7 b	(66.1)	0.321 b	57.5	50.4	0.877	88.7
Pr>F	0.0783		0.0697	0.8468	0.5195	0.9492	0.8991

^z TCSA = trunk cross sectional area^y Estimated yield in ton·ha⁻¹ given in brackets^x Means within each column with the same letter are not significantly different at p ≤ 0.05. n.s. = no significant differences

Table 14. Effect of rest breaking treatments on bud break, vegetative growth and spur quality on two-year-old shoots and return bloom, cv. Royal Gala in the Elgin area, South Africa (season 2002/2003).

Treatment	Burst buds (%)	Growing bud density according to shoot length (units·cm ⁻¹ BL ^y) ^x				Number of leaves per shoot			Leaf area per shoot (cm ²)	
		Total	<5 mm	5–10 mm	>10mm	<5mm	5–10 mm	>10 mm	<5 mm	5–10 mm
Control	81.0 b ^z	0.317	0.223 b	0.033	0.059 a	3.3	6.3 ab	8.8 a	19.5 n.s.	67.8 a
HC 0.245% + oil 4%	84.7 b	0.350	0.286 ab	0.027	0.040 ab	2.9	7.6 a	7.6 ab	21.4	78.7 a
HC 0.49% + oil 4%	84.3 b	0.334	0.243 b	0.056	0.031 ab	2.9	6.0 b	5.9 b	22.3	81.6 a
TDZ-oil 3%	98.4 a	0.369	0.300 ab	0.051	0.017 b	3.3	5.1 b	8.7 a	24.8	57.7 ab
TDZ-oil 5%	95.3 a	0.387	0.356 a	0.019	0.013 b	3.5	5.9 b	10.4 a	14.8	26.5 b
Pr>F	<0.0001	0.3477	0.0779	0.2471	0.0817	0.5130	0.0439	0.0216	0.3306	0.0661

(Cont. Table 14)

Treatment	Ring shoots			Return bloom	
	Burst buds in the ring (%)	Density (shoots · mm ⁻¹ RD ^w)	No. of leaves /shoot	(inflorescences · cm ⁻²)	(%) ^v
Control	3.2 c	0.043 b	0.8	2.176 b	23.4 a
HC 0.49% + oil 4% ^y	5.3 bc	0.110 b	0.8	1.277 b	27.2 a
HC 0.98% + oil 4%	11.1 ab	0.166 b	1.6	4.765 a	29.5 a
TDZ-oil 4%	17.5 a	0.338 a	2.1	3.297 ab	30.3 a
TDZ-oil 6%	18.8 a	0.344 a	2.2	1.561 b	13.7 b
Pr>F	0.0010	<0.0001	0.4442	0.0328	0.0045

^z Means within each column with the same letter are not significantly different at p ≤ 0.05. n.s. = no significant differences^y BL = branch length (cm)^x growing buds under the ring^w RD = ring diameter (mm)^v Reproductive buds as percentage of total buds

Table 15. Effect of rest breaking treatments on fruit set and hand thinning requirements on 'Ruby Gala' apple trees, in the Elgin area, South Africa (Season 2003/2004).

Treatment	Fruit set			Hand thinning requirement			
	Fruit density (No.·cm ⁻² BCSA) ^z	Fruitlets/100 clusters		No.·cm ⁻² TCSA ^z		Average fruitlet weight according to tree section (g)	
		Lower branch	Upper branch			Upper	Lower
Control	7.063	67.5	87.6 b ^y	6.454 ab	(208) ^x	14.9 a	13.0 ab
HC 0.245% + oil 4%	7.213	67.8	85.9 b	6.704 ab	(194)	12.4 ab	12.6 ab
HC 0.49% + oil 4%	8.133	68.4	87.4 b	5.197 b	(184)	13.0 ab	13.2 a
TDZ-oil 3%	8.669	71.4	106.0 ab	8.442 a	(295)	12.1 b	11.6 bc
TDZ-oil 5%	9.184	78.8	133.9 a	8.242 a	(284)	12.0 b	10.7 c
Pr>F	0.8518	0.9420	0.0407	0.0125		0.1229	0.0038

^z BCSA = branch cross sectional area; TCSA = trunk cross sectional area

^y Means within each column with the same letter are not significantly different at p = 0.05.

^x Number of hand thinned fruitlets per tree given in brackets

Table 16. Effect of rest breaking treatments on yield, fruit size and return bloom of 'Ruby Gala' apple trees, in the Elgin area, South Africa (season 2003/2004).

Treatment	Average yield per tree (kg)		Yield efficiency (kg cm ⁻² TCSA) ^z	Diameter (mm)	Length (mm)	Length/ diameter ratio	Average fruit mass (g)	Return bloom (%) ^w
Control	29.0 b	(43.0) ^x	0.9074 n.s. ^y	62.8 a	55.2 a	0.880	112.2 a	22.8 b
HC 0.245% + oil 4%	28.8 b	(42.6)	0.9786	62.7 a	55.1 a	0.879	112.3 a	34.1 ab
HC 0.49% + oil 4%	34.9 ab	(51.7)	0.9924	61.9 ab	54.2 ab	0.876	108.2 ab	37.8 a
TDZ-oil 3%	40.2 a	(59.6)	1.1666	60.1 c	52.7 b	0.877	98.9 c	31.1 ab
TDZ-oil 5%	32.5 b	(48.1)	0.9773	60.9 bc	53.7 ab	0.881	103.2 bc	24.0 b
Pr>F	0.0917		0.1283	0.0015	0.0285	0.9187	0.0054	0.0952

^z TCSA = trunk cross sectional area

^y n.s. = no significant differences. Means within each column with the same letter are not significantly different at p = 0.05.

^x Number of fruits hand thinned per tree given in brackets.

^w Reproductive buds as percentage of total buds

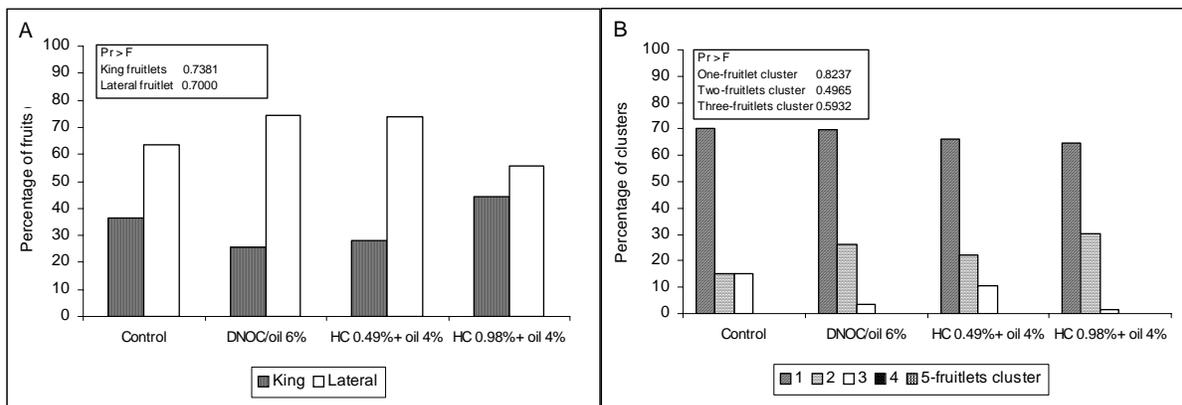


Figure 1. Fruit set pattern according to A) kind of flower set ('king' or 'lateral') and, B) fruit density per cluster on 'Golden Delicious' (season 2001/2002).

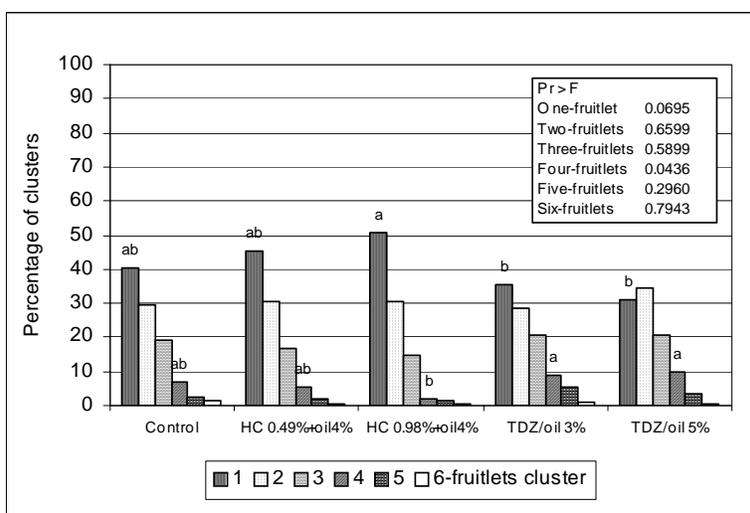


Figure 2. Fruit set pattern according to number of fruitlets per cluster on 'Golden Delicious' apples (season 2002/2003).

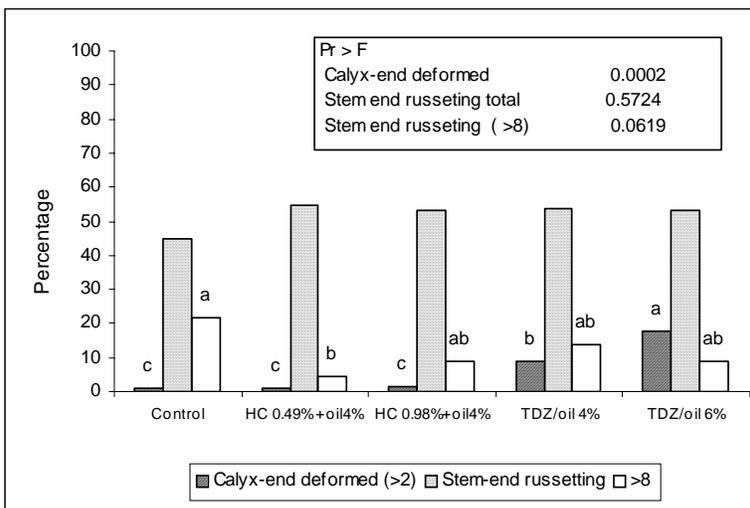


Figure 3. Effect of rest breaking treatments on the proportion of fruit with defects: malformed calyx cavity (%) and stem-end russeting (Chart A.37 Capespan, from 1 (absent) to 12 (severe) in 'Golden Delicious' (season 2002/2003).

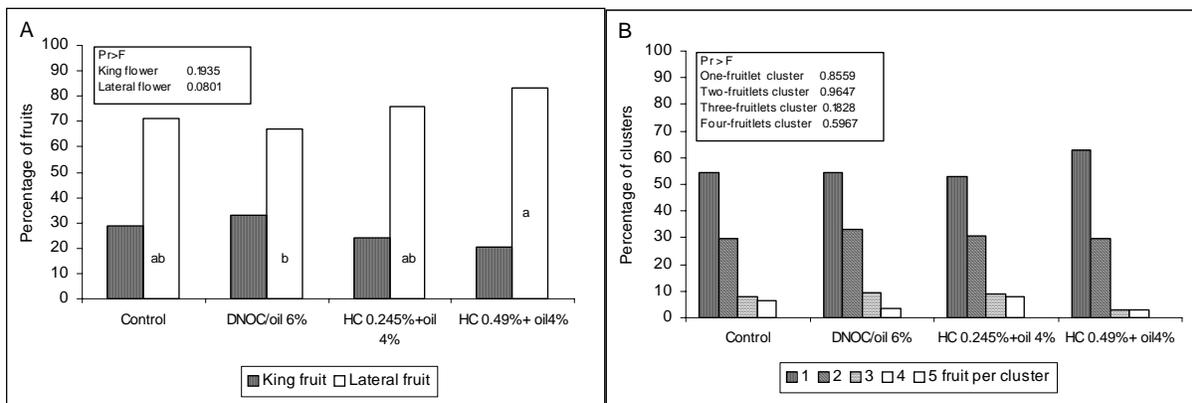


Figure 4. Fruit set pattern according to A) kind of fruit (king or lateral) and B) fruit density per cluster, Cv. Royal Gala: Elgin, South Africa. Means followed by the same letter within the same variable do not differ significantly at $p < 0.05$.

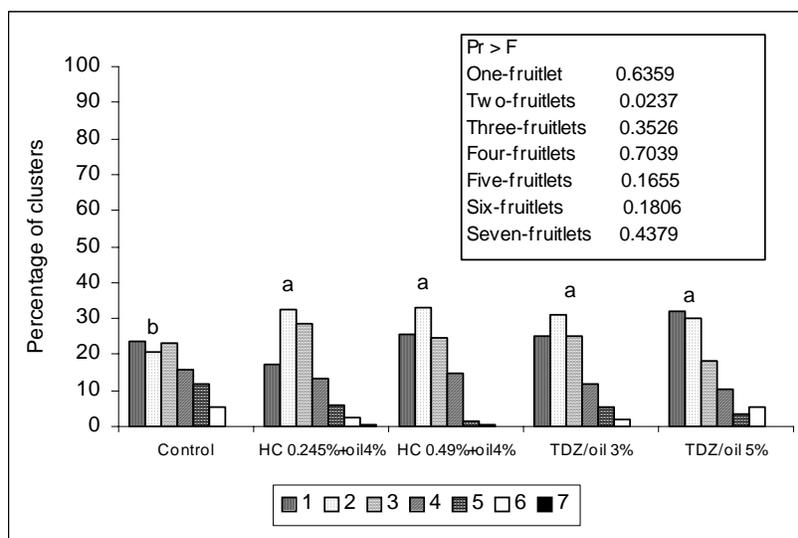


Figure 5. Fruit set pattern according to number of fruitlets per cluster, Cv. Royal Gala: Elgin, South Africa (season 2002/2003).

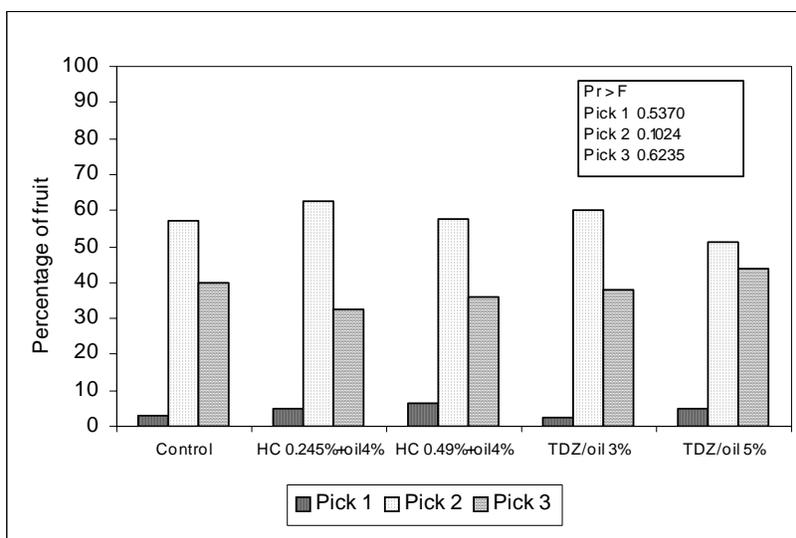


Figure 6. Harvest distribution as percentage of total yield per tree, Cv. Royal Gala: Elgin, South Africa (season 2002/2003).

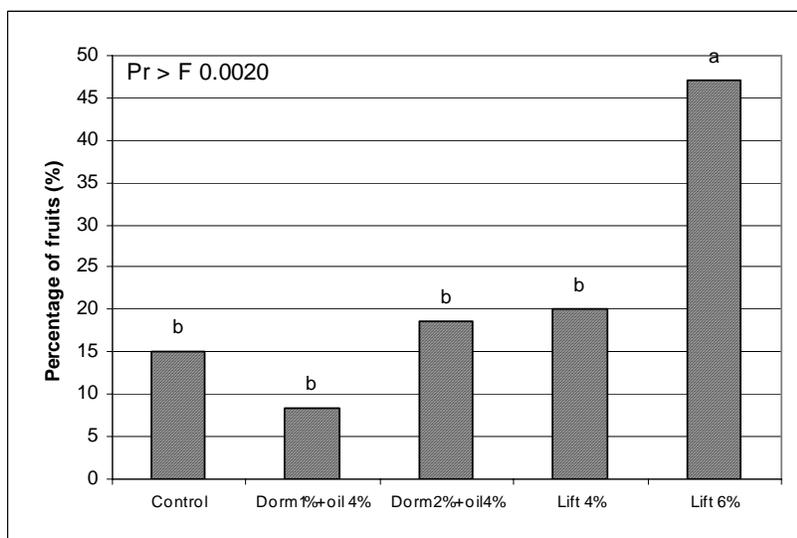


Figure 7. Effect of rest breaking treatments on the proportion of fruit with malformed calyx cavity (%) in 'Golden Delicious' (season 2003/2004).

PAPER 4: Effect of timing and rate of thidiazuron/oil application as rest-breaking treatment and thinning programs on yield and fruit quality of apple trees

Abstract

The main objective of this study was to determine whether the rate and timing of the application of thidiazuron as a rest-breaking treatment influences fruit set, yield and fruit quality. The extent to which fruit abnormalities occur and whether and how they are influenced by different cytokinin-type chemical thinning strategies was also investigated. The research was carried out in commercial apple orchards over two seasons, namely 2003-2004 and 2004-2005, in the Elgin area (34°S, 300 m), South Africa. Three experiments were performed. In the first experiment the effect of the timing (viz. early optimum and late) and rate (3% and 5%) of TDZ-oil as Lift[®] (TDZ 3 g·L⁻¹, mineral oil and adjuvants to 1L) was evaluated in the absence of any chemical thinning in ‘Golden Delicious’ and ‘Granny Smith’ apple trees. In the second experiment, the optimum recommended rate of TDZ-oil was used at different timings in ‘Golden Delicious’ and ‘Royal Gala’. In this experiment the effect of two BA (6-benzyladenine) thinning programmes were also compared. In the third experiment, the timing of the application of TDZ-oil was optimised but the rate was varied. Here the possible influence of NAA (1-naphthaleneacetic acid) or NAD (naphthalene acetamide) as part of a BA thinning programme was also evaluated in ‘Golden Delicious’. The rate and timing of TDZ-oil application influenced the reproductive development of apples and therefore fruit quality. In ‘Golden Delicious’ increased fruit set, number of seeds, and reduced fruit russeting appear as beneficial results of TDZ-oil, whereas fruit set and russeting was not affected in ‘Granny Smith’. TDZ-oil, when applied late and at increasing rates, led to an increase in the malformation of calyx cavities, especially when chemical thinning was performed using the cytokinin-like compound BA alone or in a mixture with gibberellins (BA+GA₄₊₇), NAA and NAD. The effect seemed to be cultivar specific, with ‘Golden Delicious’ being the most severely affected. Increased return bloom in response to late TDZ application in ‘Golden Delicious’ and ‘Royal Gala’ appeared to be beneficial.

Introduction

Fulfilment of the chilling requirement is necessary for deciduous fruit trees to end dormancy and to successfully flower and produce fruit (Samish, 1954; Saure, 1985; Erez, 1987). The amount of chilling required depends upon the species and cultivar (Samish, 1954; Saure, 1985; Erez, 2000). To overcome chilling inadequacies and to normalise bud burst and yield, the use of rest-breaking agents is essential in production areas with inadequate chilling (Erez, 1987). Numerous different

chemicals, including growth regulators and nutritional compounds, have been used to overcome dormancy (Saure, 1985; Erez, 1987).

Cytokinin analogs, especially thidiazuron (TDZ), have been evaluated to overcome dormancy (Steffens and Stutte, 1989; Wang *et al.*, 1991). TDZ and other chemicals that increase cytokinin concentrations in the xylem sap are not equally effective in breaking dormancy during the entire dormant period. Some chemicals are able to trigger growth in late autumn and again when about two-thirds to three-quarters of the chilling requirement of buds is satisfied (Erez, 1987; Steffens and Stutte, 1989). TDZ has the capacity to release lateral buds from dormancy in apple buds (Wang *et al.*, 1986). It also reduced the number of chilling units required to achieve bud break (Steffens and Stutte, 1989; Faust *et al.*, 1991). Alvarado-Raya *et al.* (2000) proved that TDZ at three concentrations (50, 100 and 200 mg L⁻¹) was as effective as Dormex[®] at 5 mL·L⁻¹ (hydrogen cyanamide 49%) in advancing the beginning of flowering and full bloom, and reducing the time between these two stages in 'Shiro' plum. TDZ applied at a concentration of 100 mg L⁻¹, 17 days before full bloom, increased the ovary diameter and the thickness of the ovary wall in the flower bud. It also reduced the flowering period in 'Golden Delicious' and 'Gala' apples, although this effect it not always evident under warm spring conditions (Paper 2).

Chemical thinning is widely used in commercial apple production to increase fruit size, enhance return bloom, improve quality, avoid limb breakage and reduce biennial bearing (Williams, 1979; Byers *et al.*, 1990; Ferree, 1996). 1-naphthaleneacetic acid (NAA) and 1-naphthyl N-methylcarbamate (carbaryl) are effective fruit thinners for a period of 4 to 5 weeks after full bloom (Byers *et al.*, 1990; Byers and Carbaugh, 1991). 6-Benzyladenine (BA) is an efficient agent with which to treat hard-to-thin apple cultivars (Elfving, 1989; Basak, 1996; Bound *et al.*, 1997). Greene *et al.* (1990) and Basak (1996) report that BA is effective in increasing the fruit size even in the absence of significant thinning. As most of these chemicals are sprayed at bloom or post-bloom (Greene, 1995), their efficacy could be affected by the effect of rest-breaking treatments on flowering and fruit set.

Previously it was determined that TDZ-oil (Lift[®]) at a rate of 6% resulted in abnormalities in the flowers and shoots of 'Golden Delicious' (Paper 2). TDZ-oil at 5% in 'Royal Gala' and TDZ-oil at 4% and 6% in 'Golden Delicious' enhanced bud burst and induced buds sprouting at the base of shoots in the scars left by the previous seasons bud scales and at the base of bud scars on 2-year-old wood, resulting in the growth of abnormally small leaves (Paper 3). In addition, the presence of

deformed calyx cavities was observed in 'Golden Delicious' fruit and it seemed to be exacerbated when combined with a 6-benzyladenine chemical thinning treatments (field observations).

The objective of this study was to determine whether the rate and timing of the application of thidiazuron as a rest-breaking treatment influence fruit set, yield and fruit quality. The extent to which fruit abnormalities occur and whether and how they are influenced by different cytokinin-type chemical thinning strategies was also investigated.

Materials and Methods

The research was carried out in apple orchards during two seasons, namely 2003-2004 and 2004-2005, in the Elgin area (34 °S, 300 m), Western Cape, South Africa. It consisted of five separate trials (in three experiments), two in 2003-2004 and one in 2004-2005 on 'Golden Delicious', one in 2003-2004 on 'Granny Smith', and one on 'Royal Gala' in 2004-2005.

The following chemical products were used: thidiazuron/oil (TDZ-oil) as Lift[®] (TDZ 3 g·L⁻¹, mineral oil and adjuvants to 1L); 6-benzyladenine (BA) + gibberellins (GA₄₊₇) as Promalin[®] ((phenylmethyl)-1H-purine 6-amine 1.8% + gibberellins A₄A₇ 1.8% w/w); BA as MaxCel[®] (6-benzyladenine 1.9% w/w); naphthalene acetamide (NAD) as GoldenThin[®] (2-(1-naphthyl)acetamide 10% w/w), naphthaleneacetic acid (NAA) as Planofix[®] (2-(1-naphthyl)acetic acid 45 g·L⁻¹).

In the first experiment, the effect of the timing and rate of TDZ-oil application was evaluated in the absence of any chemical thinning. In the second experiment, the optimum rate of the TDZ-oil application was used per cultivar but at different timings. Here the effect of two chemical thinning strategies that include BA, one in combination with GA₄₊₇ and NAD and another with NAA, were compared. In the third experiment the timing of application of TDZ-oil was optimised, but the rate varied. In addition, the possible influence of NAA or NAD as part of a BA + GA₄₊₇ thinning programme was evaluated.

Experiment 1. Evaluation of TDZ-oil rates and time of application on cultivars Golden Delicious and Granny Smith. 2003-2004 season.

This trial was conducted to evaluate the effect of two rates of TDZ-oil applied at three different times, viz., early, optimum, and late spraying, where optimum was the manufacturer's recommendation at 5 to 6 weeks prior to expected full bloom, early was approximately 1 to 2 weeks before optimum and late was 1 to 2 weeks after optimum. 'Golden Delicious' trees on M793 rootstock, planted in 1999 at 4 m x 1.5 m spacing, were used, with 'Royal Gala' on M793 as cross-pollinator planted in separate rows. 'Granny Smith' trees on M793 rootstock, planted in 1995 at a spacing of 4.5 m x 2.5 m were used, with 'Topred' on M793 used as cross-pollinator, planted in alternate rows. The TDZ-oil concentrations used for both cultivars were 3% and 5% of the commercial formulation Lift[®]. The application times for 'Golden Delicious' were 28 August as early spraying (742 Richardson CU), 4 September as optimum (791 CU) and 15 September as late (831 CU). For 'Granny Smith' the times were 4 September as early spraying (791 Richardson CU), 15 September as optimum (831 CU) and 22 September as late (849 CU). Treatments were sprayed as dilute spray to run-off by means of a handgun. The two rates of TDZ-oil in combination with three spraying times, plus an unsprayed control, gave seven treatments, laid out in a randomised complete block design with 10 single tree plot replications. The selected trees were trained to a central leader system and were of normal vigour, uniform, and regular bearing. All the experimental sites were orchards under standard commercial cultivation practices. To prevent over-cropping and to adjust the numbers of fruit per cluster, corrective hand thinning was done for every treatment, at the same time in both cultivars, according to commercial norms.

Experiment 2. Evaluation of interaction between spraying time of TDZ-oil and chemical thinning treatments on cultivars Golden Delicious and Royal Gala. 2003-2004 season.

These experiments were conducted to determine the presence of any interaction between the timing of TDZ-oil spraying and different chemical thinning treatments. The trials were performed in one orchard planted in 1998 at 4 x 1.4 m spacing, alternating two rows of 'Golden Delicious' and two rows of 'Royal Gala' apple trees on M793 rootstock. For each cultivar, 3% TDZ-oil (Lift[®]) was used as rest-breaking treatment at the three times as described for Experiment 1. For both cultivars, the dates of spraying were the same as described for 'Golden Delicious' in Experiment 1. The three timings of TDZ-oil applications were evaluated in combination with three thinning programmes. These were: (1) unsprayed control; (2) BA+GA₄₊₇ at 46.8 mg·L⁻¹ (Promalin 1.25 ml·L⁻¹) plus NAD at 35 mg·L⁻¹ (Goldenthin 70 mg·L⁻¹) sprayed 2-3 days after full bloom; and (3) NAA at 9.9 mg·L⁻¹ (Planofix 0.11 ml·L⁻¹) at petal drop plus BA at 100 mg·L⁻¹ (Maxcel 5 ml L⁻¹) when fruitlets were 9-12 mm in diameter.

Treatments were sprayed to run-off by means of a handgun. The experimental layout was a randomised complete block design with nine treatments and ten single tree replicates in a 3 x 3 factorial design. The experimental site was an orchard under standard commercial cultivation practices. The selected trees were trained to a central leader system and were of normal vigour, uniform and regular bearing. Corrective hand thinning was done for each treatment at the same times according to commercial norms.

Experiment 3. Evaluation of the effect of TDZ-oil application rates and chemical thinning treatments on cultivar Golden Delicious. 2004-2005 season.

This trial consisted of 10 treatments. Two rates of TDZ-oil (3% and 5% Lift[®]) were used combined with five chemical thinning programmes. The trial was performed on ‘Golden Delicious’ trees on M793 rootstock, planted in 1998 at 4 x 1.5 m spacing, with ‘Royal Gala’ on M793 as cross-pollinator, planted in separate rows. Both TDZ-oil dosage rates were sprayed on 27 August (508 CU). The chemical thinning programmes were as follows: (1) unsprayed control; (2) BA+GA₄₊₇ at 46.8 mg·L⁻¹ (Promalin 1.25 ml·L⁻¹) at full bloom; (3) BA+GA₄₊₇ at 46.8 mg·L⁻¹ (Promalin 1.25 ml·L⁻¹) at full bloom, plus NAD at 35 mg·L⁻¹ (Goldenthin 70 mg·L⁻¹) 2 days later; (4) the same rate of BA+GA₄₊₇ and NAD as in the previous treatment sprayed 2 days after full bloom; and (5) BA+GA₄₊₇ at 46.8 mg·L⁻¹ at full bloom plus NAA at 9.9 mg·L⁻¹ (Planofix 0.11 ml·L⁻¹) at petal drop. Treatments 2-5 received a second application of BA+GA₄₊₇ (at the same rate) 14 days after full bloom. No surfactants were used. Treatments were sprayed to run-off by means of a handgun. The experimental design was a randomised complete block with 10 treatments and 10 single tree replicates. The selected trees were trained to a central leader system and were of normal vigour, uniform, and regular bearing. All the experimental sites were orchards under standard commercial cultivation practices. Corrective hand thinning was done according to commercial norms.

Data recorded

Fruit set was determined on two tagged branches per tree by counting the number of flower clusters at full bloom and expressing the number of fruitlets 30 days after full bloom (DAFB) as a proportion of fruit per hundred clusters. The total number of fruit removed by hand thinning 30 DAFB was recorded. Yield (kg/tree) and yield efficiency (kg·cm⁻²) were calculated from the yield and the trunk cross-sectional area (TCSA) in cm² as measured 25 cm above the soil surface. Fruit quality was assessed using all fruit from one branch per tree. The number of viable-appearing seeds per fruit was counted. Fruit quality variables were: fruit size (mass, length, diameter), fruit ground colour (graded from 1 (green) to 6 (yellow)), foreground colour (chart A42 Capespan Pty PO Box

505. Cape Town 7535, from 1 to 12 (1 full red)), stem-end russeting (charts A43 and A40 Capespan, from 1 to 12 (most severe)), retiform russeting (chart A37 Capespan, from 1 to 11 (most severe)). The presence of fruit with a wrinkled or malformed calyx cavity was also recorded (see Figure 1). Return bloom was determined on the same two branches as for fruit set by counting the number of vegetative and reproductive growing buds the following spring.

Data analysis

All data were subjected to analysis of variance using the General Linear Model (GLM) procedure of the Statistical Analysis System program (SAS Institute, Cary, NC). Single degree of freedom and orthogonal polynomial contrasts were fitted.

Results

Experiment 1

‘Golden Delicious’: Fruit set per 100 clusters was not influenced by the rate or timing of TDZ-oil application in ‘Golden Delicious’ (Table 1). However, the number of fruitlets that needed to be hand-thinned was increased by TDZ-oil applications when compared to the unsprayed control ($p=0.0136$). The rate of TDZ-oil dosage did not influence this factor, but from the timing of the TDZ-oil application it is clear that the optimum timing increased the number of fruit that had to be hand-thinned more than the early or late applications ($p=0.0549$). Yield of ‘Golden Delicious’ was not significantly affected when expressed as kg per tree or as yield efficiency. Return bloom was improved the following spring by the later application of TDZ-oil (Table 1).

Fruit size (fruit mass, length and diameter) was improved by the 3% TDZ-oil application in comparison to the 5% application, but the increase decreased linearly the later the applications were made (Table 2). There was no significant effect on fruit shape. The TDZ-oil application resulted in fruit with higher numbers of seeds than the unsprayed control, but the rate of application was not significant. Furthermore, the later the application, the smaller was the improvement in the number of seeds (Table 2).

The effect of the TDZ-oil application on fruit quality was significant in that the average stem-end russet was reduced compared to the control ($p=0.0069$) and the later the application the greater was the reduction. The percentage of fruit (with a score >8) that was not exportable due to stem-end russeting also decreased linearly with application date (Table 3). In terms of retiform russet, values were very low and no significant effect on the percentage of fruit that was exportable was observed,

even though the average russet decreased linearly with application date. Malformation of ‘Golden Delicious’ fruit at harvest was on average significantly higher following the higher rate (5%) of TDZ-oil application compared to the 3% application (Table 3). 5% TDZ-oil also increased malformation compared to the control, but the increase was only significant for the late application.

‘Granny Smith’: Fruit set, as the number of fruits per hundred clusters, and the hand thinning requirement were not affected by the rate and timing of the TDZ-oil application compared to the control treatment (Table 4). The total yield and yield efficiency were also not influenced by TDZ-oil treatments compared to the control. However, the 5% TDZ-oil affected the yield efficiency negatively in comparison to the 3% rate ($p=0.0179$); it reduced the efficiency by approximately 25%. Return bloom was not significantly affected by TDZ-oil (compared to the control), but the time of spraying had a marked effect with the optimum timing increasing the return bloom more than the early or late applications ($p=0.0094$).

There was a slight reduction in fruit diameter in response to TDZ-oil treatments (Table 5). Early applications reduced the fruit mass, diameter, and length in comparison to the control, and there was a linear increase in fruit size the later the applications were made. There was a slight decrease in length-to-diameter ratio with earlier applications of TDZ-oil. On average, TDZ-oil seemed to have decreased the length-to-diameter ratio of fruit compared to the control ($p=0.0684$). The TDZ-oil increased the number of seeds, compared to the control ($p=0.0311$), but the rate of application was not significant (Table 5). There was a quadratic effect on average stem-end russetting in response to timing of TDZ-oil being higher with the optimum application, but the level were very low and the percentage of fruit that was not exportable was not affected (Table 6). Malformation of the fruit calyx cavity was low, with only the late 5% TDZ-oil application inducing a significant percentage of affected fruit (Table 6).

Experiment 2

‘Golden Delicious’: There was a significant interaction between TDZ-oil and thinning treatments in fruit set (Table 7). Set was strongly reduced by the BA+GA₄₊₇ application in combination with NAD thinning treatment on trees where the TDZ-oil was applied late. However, there was no interaction in terms of the number of fruit that had to be removed by hand thinning (Table 8). The optimum TDZ-oil concentration increased hand thinning requirements compared to the early and late applications, whereas chemical thinning treatments reduced the need for this practice. Here the BA+GA₄₊₇ + NAD treatment was the most effective (Table 8). Yield efficiency was reduced by late TDZ-oil application, but unaffected by chemical thinning. Return bloom increased the later TDZ-

oil applications the later the application was made (Table 8). Return bloom was also increased by chemical thinning with BA+GA₄₊₇ + NAD being more effective than NAA + BA.

In terms of fruit size, fruit diameter was reduced by optimum and late TDZ-oil applications, whereas the chemical thinning treatments increased fruit diameter, length, and mass (Table 9). The optimum TDZ-oil application seemed to have decreased fruit mass compared to the early treatment ($p=0.0551$). The fruit length-to-diameter ratio was slightly increased by the BA+GA₄₊₇ + NAD thinning treatment. The number of seeds was slightly reduced by the late TDZ-oil application, as well as by the BA+GA₄₊₇ + NAD thinning treatment compared to the control (Table 9).

Fruit maturity, evaluated as starch breakdown, was delayed compared to the early application when the application was carried out later (Table 10), but fruit colour was not significantly affected (data not shown). Starch breakdown was not significantly influenced by thinning treatments.

Regarding fruit quality, the average score for stem-end russeting was slightly increased by the early TDZ-oil application compared to the optimum ($p=0.0548$). However, there was no effect on the percentage of fruit with score >8 , even though these levels were still relatively low (Table 10). TDZ-oil treatments did not affect significantly the incidence of retiform russeting. NAA + BA thinning treatment increased the average score for stem end russeting compared to BA+GA₄₊₇ + NAD, but this did not affect the percentage of fruit that was exportable. NAA + BA thinning treatment also increased the retiform russet intensity compared to the control and BA+GA₄₊₇ + NAD resulting in a higher percentage of non-exportable fruit (Table 10). The percentage of malformed calyx cavities increased with the later applications of TDZ-oil when combined with a chemical thinning treatment (Table 11). TDZ-oil application time had no effect on malformation in the absence of chemical thinning. Malformation was more pronounced with BA+GA₄₊₇ + NAD than with NAA + BA. Early TDZ-oil application followed by thinning with NAA + BA did not significantly increase malformation compared to the control.

‘Royal Gala’: For most of the variables there was no interaction between TDZ-oil application time and thinning treatments, except in the case of fruit size. Fruit set, as the number of fruits per hundred clusters, was not affected by TDZ-oil treatments, but chemical thinning reduced it significantly, to less than 50 fruit per 100 clusters with BA + GA₄₊₇ and NAD being the most effective (Table, 12). The hand thinning requirement was higher at the optimum TDZ-oil spraying time compared to the early application and was reduced by the chemical thinning being lower following the BA+GA₄₊₇ and NAD treatment (Table 12). TDZ-oil application time did not influence

yield, whereas BA+GA₄₊₇ + NAD thinning reduced it significantly. Return bloom was increased by the later TDZ-oil application and by BA+GA₄₊₇ + NAD thinning (Table 12).

Interaction occurred between TDZ-oil application time and thinning treatments in terms of fruit size (diameter, length, and mass). BA+GA₄₊₇ + NAD when combined with optimum and later TDZ-oil application increased fruit size (Table 13). Fruit shape was influenced very slightly, with longer fruit resulting when BA+GA₄₊₇ + NAD was applied (Table 14). Late TDZ-oil application decreased the length-to-diameter ratio. The number of seeds was increased by the late TDZ-oil application and slightly reduced by the chemical thinning treatments (Table 14). With respect to fruit quality, little stem-end russeting was detected, and there was a slight reduction in russeting with optimum and late TDZ-oil application (Table 14). Ground colour was increased into a small extent by the early TDZ-oil application compared to later application and by BA+GA₄₊₇ + NAD applications. Foreground colour appeared to be reduced (less red) by the late compared to the early TDZ-oil application and improved by the BA+GA₄₊₇ + NAD treatment. Three picks were done according to colour, harvesting the best-coloured fruit (>50% red foreground) first. Late TDZ application resulted in a lower percentage of fruit on the first pick, whereas BA+GA₄₊₇ + NAD increased the amount of fruit on the first pick (Figure 2). The malformation of the calyx cavity was generally low, but significantly higher following the BA+GA₄₊₇ + NAD thinning treatment (Table 14).

Experiment 3

'Golden Delicious': Fruit set was reduced by the chemical thinning treatments (Table 15). BA+GA₄₊₇ had a stronger effect when followed by NAD or NAA application, at both 3% and 5% TDZ-oil. There was no significant difference on fruit set between the two rates of TDZ-oil application (Table 15), although the need for hand thinning was increased by the 5% TDZ-oil treatment ($p=0.0132$) compared to the 3% application. The control treatment at 5% required heavier hand thinning than all the other treatments. The control at 3% TDZ-oil also required heavier thinning except for the combination of TDZ-oil and BA+GA₄₊₇ on its own. (Table 15). Yield efficiency was significantly decreased by the chemical thinning treatments ($p=0.0056$) in comparison to the control, but was unaffected by the application rates of TDZ-oil (Table 15). BA+GA₄₊₇ reduced yield efficiency most significantly when combined in the tank mix with NAD or followed by NAA application. However, none of the treatments decreased yield compared to the control.

In terms of fruit size and fruit shape, there was no significant effect of TDZ-oil application rates (Table 16). Chemical thinning generally increased fruit size, especially BA+GA₄₊₇ combined with

NAD or followed by NAA (thinning 4 and 5) by increasing the fruit diameter, length and mass. The number of seeds per fruit was not affected by TDZ-oil concentration, but was reduced by thinning treatments except if BA+GA₄₊₇ was followed by NAA (Table 17).

The percentage of non-exportable fruit due to stem-end russet was generally low (less than 3%), and the chemical thinning treatments in general had a positive effect in terms of reducing this problem (Table 17). Retiform russeting was affected by TDZ-oil rates. At 5% TDZ-oil resulted in a higher percentage of non-marketable fruit when the thinning was performed with applications of BA+GA₄₊₇ and NAD. The presence of malformed calyx cavities was strongly influenced by the chemical thinning treatments, it being less than 1% in the control treatments. The problem increased when BA+GA₄₊₇ was combined with NAD and NAA, where the percentage of affected fruit was more than 10% (Table 17).

Discussion

It was generally found that the TDZ-oil application improved fruit set, but this was dependent on the time of application and the cultivar. In ‘Golden Delicious’ the fruit set, determined as number of fruit per hundred clusters, was not affected by TDZ-oil treatments, but the number of fruits that had to be removed by hand-thinning was increased. This indicates a higher fruit load per tree, since the hand-thinning criteria were the same for each treatment. This could be due to a higher number of clusters per tree. In addition, an improvement in the set potential was observed as an increased number of seeds per fruit. A time effect was also detected; it appears that a positive effect can be obtained by optimising the application time, since hand thinning was less following the late and early applications. The number of seeds was increased by TDZ-oil in ‘Granny Smith’ and ‘Golden Delicious’. In ‘Golden Delicious’, a linear decrease in seed number was observed with later application, while in ‘Royal Gala’ late application of TDZ-oil increased the seed number compared to earlier applications.

TDZ-oil did not show a clear effect on yield and yield efficiency in ‘Golden Delicious’. An interactive effect between the rate or timing of TDZ-oil application and the thinning treatment used was observed. Late TDZ-oil application without chemical thinning gave a higher fruit set being similar to early TDZ-oil. A detrimental effect on fruit set was observed when late TDZ-oil at 5% was followed by BA+GA₄₊₇ thinning treatment.

'Granny Smith' appeared not to be affected by TDZ-oil rates and application time in terms of fruit set, but yield efficiency was reduced by TDZ-oil at 5%. This could have been due to a negative or phytotoxic effect following the higher rate, resulting in a reduced crop load per tree. TDZ has effect as a thinning agent has been used as thinning agent in apple. TDZ thinning treatment induced a high reduction on fruit set in apple (Greene, 1995). The timing of the 3% TDZ-oil application did not influence fruit set in 'Royal Gala'. However, the optimum application date increased the hand thinning requirement compared to the early application, which is suggesting an increase in crop load compared to the early application.

The rest-breaking treatment application coincides with a time when reproductive buds go through a phase of strong growth and intense cell division (Bergh, 1985; Faust, 1989; Wang *et al.*, 1991; Jackson, 2003). Buds at this stage could be sensitive to cytokinin applications. The stage of flower bud development at any given time during summer and autumn varies with the type of bud and with cultivar (Crabbé, 1984). Nevertheless, buds continue to develop through the winter (Wang and Faust, 1990). Apple buds increase in size by 20-25% during December and January (NH) and by an additional 120-150% between mid-February and mid-March (Jackson, 2003). This was observed under cold winter climatic conditions. Similar results were observed by Bergh (1985) in 'Starking' apple in the same area as where this study was conducted. He found that carpels grew upwards, sepals and petals elongated, and pollen sacs developed towards the end of August (SH). Ovule primordia were distinguishable toward the end of this period, approximately 21 days before anthesis. Swelling of buds coincided with the acceleration of elongation of the carpels, formation of pollen sacs and elongation of the filaments of the stamens. TDZ releases buds from dormancy, inducing several metabolic changes (Wang *et al.*, 1986; Wang *et al.*, 1991). Increased gibberellins and cytokinin levels have been reported in 'Anna' apples following TDZ application (Bondok *et al.*, 1995).

TDZ application could be increasing the ovule fertility or longevity up to a certain stage of bud development; this could explain the increase in the number of seeds observed in this study. Another factor that could also explain the higher number of seeds observed in 'Golden Delicious' and 'Granny Smith' after TDZ-oil treatment is the increased vegetative bud burst induced by TDZ (Papers 2 and 3). The primary spur leaves, while small, are important as their condition and rate of development affect fruit set (Ferree and Palmer, 1982). Hence, the stimulating effect of TDZ-oil on spur leaf development could possibly increase seed number. On the other hand, the stimulating effect of late TDZ-oil application on bud burst may increase competition between vegetative and reproductive growth, thereby reducing seed number of seed as seen in 'Golden Delicious'. The

more rapid onset of vegetative growth in response to TDZ-oil could increase spur quality and assimilated transport to the buds, resulting in an increased return bloom. The effective spur leaf area is an important factor in flower initiation (Monselise and Goldschmidt, 1982). Flower bud induction on spurs occurs in the three to six weeks after full bloom (Bubán and Faust, 1982). Hence, the earlier the spurs reach the stage to be induced (number of nodes) and the more leaf area per spur, the better will be the quality of the bud and the consequent inflorescence.

In ‘Golden Delicious’ the return bloom was improved by late TDZ-oil application. This effect was also observed in ‘Royal Gala’ trial, whereas ‘Granny Smith’ responded better to the optimum time. When TDZ was applied as a thinning agent, the results on fruit set and return bloom has been variable (Greene, 1995). TDZ reduced return bloom in ‘McIntosh’ and ‘Delicious’ (Greene, 1995), but not in ‘Empire’ (Elfving and Cline, 1993; Greene, 1995) and ‘Gala’ apples (Amarante *et al.*, 2002). Based on these different results, Greene (1995) suggests that the effect on return bloom appears to be cultivar specific, and that TDZ seems to have a direct effect on flower bud formation. In earlier research carried out during 2002/2003 season, aimed at evaluating the interaction between rest breaking treatments and chemical thinning, return bloom was reduced by TDZ-oil at 6% in ‘Golden Delicious’ (unpublished data). Therefore, a higher rate of TDZ-oil can also be detrimental. This could be due to excessive vegetative growth.

The presence of calyx cavity malformation was dependent on the rate and timing of TDZ-oil application. Generally, the higher the rate of TDZ-oil and the later the application was made, the higher the incidence of malformation. Malformation due to TDZ has been reported when it was used as a chemical thinning agent in apples (Curry and Greene, 1993; Greene, 1993). An increase in fruit size (Elfving and Cline, 1993; Greene, 1995; Amarante *et al.*, 2002), and length-to-diameter ratio has also been reported (Greene, 1995). The enhanced fruit set and return bloom may be inhibited at high concentrations of TDZ in some cultivars (Elfving and Cline, 1993; Greene, 1995). However, when it was used as a rest-breaking treatment it increased ovary size (diameter and ovary wall thickness) in plums (Elfving and Cline, 1993; Alvarado-Raya *et al.*, 2000).

In Experiment 1 in ‘Golden Delicious’, where timing and rate combinations were evaluated, there was a higher incidence of malformed cavities following the 5% TDZ-oil application, but no effect of timing of application. In Experiment 2, where in the same year and under similar conditions three application times of 3% TDZ-oil were evaluated in combination with chemical thinning, the presence of malformed calyx cavities was enhanced the later the application was made. Although the interaction between timing and rate of TDZ-oil was not evaluated in this experiment, it seems

that the effect on malformation could be further increased by later application at the higher rate. In this regard, TDZ with its cytokinin-like activity would be enhancing cell division at this sensitive stage of development. The effect of cytokinins on cell division is well documented (Letham and Williams, 1969). In this present study, the malformation observed in the calyx cavity could be attributed to an excessive growth of the flower receptacle, by the TDZ action itself or by its effect on increasing the production of cytokinins and gibberellins (Bondok *et al.*, 1995). The sepals and petals are the first parts formed in the flower primordia before leaf fall (Bergh, 1985; Faust, 1989), and in 'Starking' apple are well developed by the end of winter (Bergh, 1985). This tissue could have been more developed and receptive at the later TDZ application times, thus it could be inferred that the later the application the stronger the effect.

In this study, where the interaction between TDZ-oil and chemical thinning treatments was assessed, the malformation was enhanced by the chemical thinning treatments. Interaction between time of TDZ-oil application at 3% and chemical thinning was detected in 'Golden Delicious'. The problem was strongly enhanced by BA+GA₄₊₇ when TDZ-oil was applied late. Results of Experiment 3 showed that BA+GA₄₊₇ increased the presence of malformation especially when combined with NAA or NAD, but the TDZ-oil rate had no significant effect.

Promalin[®] (BA+GA₄₊₇) is used commercially to elongate apples (Unrath, 1974). It is applied at full bloom for maximum response, but later applications may have some thinning effect (Unrath, 1974). A thinning effect was also observed when Promalin[®] was applied at full bloom (Stembridge and Morrell, 1972). Cell division occurs during the time that chemical thinning is applied, about 14 to 18 days after full bloom (Letham and Williams, 1969). BA+GA₄₊₇ was therefore acting as a thinning treatment and also enhancing the TDZ-oil effect on cell division, resulting in the increased presence of malformed calyx cavities. On the other hand, a synergistic effect on malformation was observed when BA+GA₄₊₇ was applied in combination with NAD and NAA. These combinations also reduced fruit set and increased fruit size. The enhanced effect on malformation is probably associated with the faster fruit growth due to reduced fruit numbers. A larger flower receptacle with more cells would have greater potential to respond to the BA+GA₄₊₇. An enhanced effect on malformation was observed from rates of TDZ-oil at 4% and 6% and chemical thinning performed with BA+GA₄₊₇ and NAD, and also when only BA was used (unpublished data).

The effect of BA as a thinning treatment on cell division and fruit size has been documented (Greene *et al.*, 1990; Greene, 1993). It appears that an early application of BA has a stronger effect on cavity calyx growth than a latter application. In Experiment 2, 'Golden Delicious' fruit size was

similar after NAA plus BA treatment (BA applied at 9-12 mm fruitlet diameter) and BA+GA₄₊₇ plus NAD treatment (BA applied at full bloom), but the incidence of malformation was higher with BA+GA₄₊₇ plus NAD. However, we cannot discard the possibility that a combined effect of BA and GA₄₊₇ may have an additive effect acting on increase calyx cavity malformation.

The results of TDZ-oil applications on calyx cavity malformation appear to be cultivar specific. In 'Granny Smith', malformation was increased by late TDZ-oil at 5%. A linear effect was detected in fruit size by the application time of TDZ-oil, and only the 5% increased size significantly the late 5% TDZ-oil application. In the case of 'Royal Gala' treated with 3% TDZ-oil (Experiment 2) the incidence of malformation was very low (< 2%), and not influenced by the application time in a one-year study, although BA+GA₄₊₇ elongated the fruit.

Fruit russeting was generally reduced when the TDZ-oil application was made later and also reduced when chemical thinning was performed with BA+GA₄₊₇, but in Experiment 3, retransform russeting in 'Golden Delicious' was on average higher following 5% compared to 3% TDZ-oil. Cultivars differ greatly in their propensity to russet (Jackson, 2003), and this was also observed in the present study. The effect of gibberellins which increase the plasticity of fruitlets' skin tissue (Taylor and Knight, 1986) plays a major role in the reduction of russeting. As an indirect effect on cell division, the plasticity of the fruit skin could increase and thereby reduce the incidence of russeting.

In Experiment 2 in 'Golden Delicious', starch breakdown was slightly decreased by late TDZ, which means a delay in maturity. Excessive vegetative growth increases the availability of assimilates and may thereby increased fruit growth. Prolonged vegetative growth delays maturity. (Forshey and Elfving, 1989). In 'Royal Gala', foreground colour was reduced. This also could be due to more leaf area, less light available for fruit colour development and delayed maturity.

Conclusion

In conclusion, the rate and time of TDZ-oil application, when applied as a rest-breaking treatment, influence the reproductive development of apples and hence fruit quality. Increased fruit set, the number of seeds, and reduced fruit russeting appear as beneficial results of TDZ-oil on its own; but are dependent on the cultivar, application rate, and time of application. TDZ-oil when applied late and at increasing rates increases the malformation of calyx cavities, especially when chemical thinning is performed using cytokinin-like compounds, such as BA alone or in a mixture with

gibberellins (BA+GA₄₊₇), NAA and NAD. The effect seems to be cultivar specific, with 'Golden Delicious' most severely affected. Increased return bloom from late TDZ application appears to be beneficial, although it is also highly dependent on the cultivar and application time and rate.

Literature Cited

- Alvarado-Raya, H., Rodríguez-Alcázar, J., Calderón-Zavala, G. and Cárdenas-Zoriano, E., 2000. Thidiazuron, flower budbreak and ovary dimensions in Japanese plum (*Prunus salicina* L.) 'Shiro'. *Agrociencia* 34: 321-327.
- Amarante, C.V., Ernani, P.R., Blum, L.E. and Megguer, C.A., 2002. Thidiazuron effects on shoot growth, return bloom, fruit set and nutrition of apples. *Pesquisa Agropecuaria Brasileira* 37: 1365-1371.
- Basak, A., 1996. Benzyladenine (BA) as an apple fruitlet thinning agent-preliminary results. *HortScience* 28: 54-57.
- Bergh, O., 1985. Morphogenesis of *Malus domestica* cv. Starking flower buds. *South African Journal of Plant and Soil* 2: 187-190.
- Bondok, M.A., Abdel-Hamid, N. and El-Wakeel, H.F., 1995. Bud break, fruit maturity and yield of "Anna" apple as influenced by plant bioregulator "Thidiazuron". *Annals of Agricultural Science (Cairo)* 40: 343-358.
- Bound, S.A., Jones, K.M. and Oakford, M.J., 1997. Post-bloom thinning with 6-benzyladenine. *Acta Horticulturae* 463: 493-499.
- Bubán, T. and Faust, M., 1982. Flower bud induction in apple trees: Internal control and differentiation. *Horticultural Reviews* 4: 174-203.
- Byers, R.E., Barden, J.A. and Carbaugh, D.H., 1990. Thinning spur 'Delicious' apple by shade terbacil, carbaryl, and ethephon. *Journal of the American Society for Horticultural Science* 115: 9-13.
- Byers, R.E. and Carbaugh, D.H., 1991. Effect of chemical thinning sprays on apple fruit set. *HortTechnology* 1: 41-48.
- Crabbé, J., 1984. Vegetative vigor control over location and fate of flower buds, in fruit trees. *Acta Horticulturae* 149: 55-63.
- Curry, E.A. and Greene, D.W., 1993. CPPU Influences fruit quality, fruit set, return bloom, and preharvest drop of apples. *HortScience* 28: 115-119.
- Elfving, D.C., 1989. N-(phenylmethyl)-1H-purine-6 amine (BA) as a chemical thinner for 'Idared' apple. *Acta Horticulturae* 239: 357-362.
- Elfving, D.C. and Cline, R.A., 1993. Cytokinins and ethephon affect crop load, shoot growth, and nutrient concentration of 'Empire' apple trees. *HortScience* 28: 1011-1014.
- Erez, A., 1987. Chemical control of budbreak. *HortScience* 22: 1240-1243.

- Erez, A. 2000. Bud dormancy; phenomenon, problems and solutions in the tropics and subtropic. In: Erez, A. (Ed.), *Temperate fruit crops in warm climate*, pp. 17-48. Bet-Dagan: Kluwer Academic Publishers. 48 pp.
- Faust, M., 1989. *Physiology of temperate zone fruit trees*. 338 pp.
- Faust, M., Millard, M.M. and Stutte, G.W., 1991. Bound versus free water in dormant apple buds-a theory for endodormancy. *HortScience* 26: 887-890.
- Ferree, D.C., 1996. Performance of benzyladenine as a chemical thinner on eight apple cultivars. *Journal of Tree Fruit Production* 1: 33-50.
- Ferree, D.C. and Palmer, J.W., 1982. Effect of spur defoliation and ringing during bloom on fruiting, fruit mineral level, and net photosynthesis of 'Golden Delicious' apple. *Journal of the American Society for Horticultural Science* 107: 1182-1186.
- Forshey, C.G. and Elfving, D.C., 1989. The relationship between vegetative growth and fruiting in apple trees. *Horticultural Reviews* 11: 229-287.
- Greene, D.W., 1993. A review of the use of benzyladenine (BA) as chemical thinner for apples. *Acta Horticulturae* 329: 231-236.
- Greene, D.W., 1995. Thidiazuron effects on fruit set, fruit quality, and return bloom of apples. *HortScience* 30: 1238-1240.
- Greene, D.W., Autio, W.R. and Miller, P., 1990. Thinning activity of benzyladenine on several apple cultivars. *Journal of the American Society for Horticultural Science* 115: 394-400.
- Jackson, J.E. 2003. *Flowers and fruits. Biology of apples and pears*, pp. 268-340. Cambridge: 340 pp.
- Latham, D.S. and Williams, M.W., 1969. Regulators of cell division in plant tissue. VIII. The cytokinins of the apple fruit. *Physiologia Plantarum* 22: 925-936.
- Monselise, S.P. and Goldschmidt, E.E., 1982. Alternate bearing in fruit trees. *Horticultural Reviews* 4: 128-173.
- Samish, R.M., 1954. Dormancy in woody plants. *Annual Review of Plant Physiology* 5: 183-204.
- Saure, M.C., 1985. Dormancy release in deciduous fruit trees. *Horticultural Reviews* 7: 239-300.
- Steffens, G.L. and Stutte, G.W., 1989. Thidiazuron substitution for chilling requirement in three apple cultivars. *Journal of Plant Growth Regulation* 8: 301-307.
- Stembridge, G.E. and Morrell, G., 1972. Effect of gibberellins and 6-benzyladenine on the shape and fruit set of 'Delicious' apples. *Journal of the American Society for Horticultural Science* 97: 464-467.
- Taylor, D.R. and Knight, J.N., 1986. Russeting and cracking of apple fruit and their control with plant growth regulators. *Acta Horticulturae* 179: 819-820.
- Unrath, C.R., 1974. The commercial implications of gibberellins A4A7 plus benzyladenine for improving shape and yield of 'Delicious' apples. *Journal of the American Society for Horticultural Science* 99: 381-384.

- Wang, S.Y. and Faust, M., 1990. Changes of membrane lipids in apple buds during dormancy and budbreak. *Journal of the American Society for Horticultural Science* 115: 803-808.
- Wang, S.Y., Jiao, H.J. and Faust, M., 1991. Changes in metabolic enzyme activities during thidiazuron-induced lateral budbreak of apple. *HortScience* 26: 171-173.
- Wang, S.Y., Steffens G.L. and Faust, M., 1986. Breaking bud dormancy in apple with a plant bioregulator, thidiazuron. *Phytochemistry* 25: 311-317.
- Williams, M.W., 1979. Chemical thinning of apples. *Horticultural Reviews* 1: 270-300.

Table 1. Effect of rates and timing of TDZ-oil (Lift®) application on fruit set, hand thinning intensity, yield and return bloom of 'Golden Delicious' (Experiment 1).

Treatment	Fruit set (Number of fruits/100 clusters)	Hand-thinning intensity (fruitlets/cm ² TCSA) ^x	Average yield per tree (kg)	Yield efficiency (kg · cm ⁻² TCSA)	Return bloom (%)
Control	229 n.s.	4.03 c	27.85 (41.3) ^z	0.438 n.s.	12.9 bc
3% Lift early ^w	218	4.67 bc	33.85 (50.1)	0.482	11.8 bc
3% Lift optimum	248	5.64 ab	34.53 (51.1)	0.523	13.5 bc
3% Lift late	232	5.26 abc	36.97 (54.8)	0.537	24.1 a
5% Lift early	209	5.73 ab	31.70 (46.9)	0.480	11.2 c
5% Lift optimum	235	6.17 a	32.75 (48.5)	0.559	18.8 ab
5% Lift late	210	4.57 bc	29.31 (43.4)	0.459	22.5 a
Significance level (Pr>F)					
Treatment	0.7921	0.0302	0.5039	0.5555	0.0027
Contrast					
Control vs TDZ-oil	0.8595	0.0136	0.1396	0.1957	0.1078
Lift 3% vs Lift 5%	0.8595	0.4357	0.1566	0.7155	0.8240
TDZ-oil time linear	0.8553	0.3960	0.9369	0.8425	<0.0001
TDZ-oil time quadratic	0.1490	0.0549	0.8024	0.2104	0.8631

^w Early = 28 Aug, optimum = 4 Sep, late = 15 Sep

^x TCSA = trunk cross sectional area

^y n.s. = No significant differences

Means within each column with the same letter are not significantly different at $p \leq 0.05$.

^z Estimated yield in ton·ha⁻¹ in brackets.

Table 2. Effect of rates and timing of TDZ-oil (Lift®) application on fruit size and number of seed of 'Golden Delicious' (Experiment 1).

Treatment	Fruit diameter (mm)	Fruit length (mm)	Fruit length: diameter ratio	Fruit mass (g)	Number of seeds /fruit
Control	65.7 b ^x	60.3 b	0.916 n.s.	127.0 b	6.82 c
3% Lift early ^y	68.4 a	63.3 a	0.926	143.1 a	8.07 a
3% Lift optimum	65.9 b	60.7 b	0.921	128.1 b	7.62 ab
3% Lift late	64.7 b	59.6 b	0.921	123.2 b	7.28 bc
5% Lift early	65.8 b	60.7 b	0.923	126.9 b	7.71 ab
5% Lift optimum	65.0 b	59.9 b	0.922	124.5 b	8.10 a
5% Lift late	63.8 b	59.3 b	0.927	117.0 b	7.42 b
Significance level (Pr>F)					
Treatment	0.0052	0.04 71	0.8291	0.0020	0.0002
Contrast					
Control vs TDZ-oil	0.8726	0.7433	0.2142	0.9786	0.0001
Lift 3% vs Lift 5%	0.0220	0.0800	0.7667	0.0099	0.5904
TDZ-oil time linear	0.0006	0.0070	0.8907	0.0005	0.0052
TDZ-oil time quadratic	0.4093	0.3614	0.5273	0.4097	0.2976

^y Early = 28 Aug, optimum = 4 Sep, late = 15 Sep

^z Means within each column with the same letter are not significantly different at $p \leq 0.05$.

n.s. = No significant differences

Table 3. Effect of rates and timing of TDZ-oil (Lift[®]) application on fruit quality of ‘Golden Delicious’ (Experiment 1).

Treatment	Stem-end russeting score ^x		Retiform russeting score ^x		Malformed calyx cavity (%)
	Average	Score >8 (%)	Average	Score >4 (%)	
Control	3.06 a ^z	2.60 a	0.16 c	0.00 n.s.	6.56 bcd
3% Lift early ^y	2.83 ab	2.47 ab	0.35 ab	0.90	7.17 bcd
3% Lift optimum	2.37 bc	0.91 bc	0.21 bc	0.32	5.79 cd
3% Lift late	2.22 c	0.00 c	0.15 c	0.67	3.62 d
5% Lift early	2.82 ab	2.54 ab	0.40 a	1.66	12.32 abc
5% Lift optimum	2.66 abc	1.28 abc	0.31 abc	0.97	13.87 ab
5% Lift late	2.24 c	0.31 c	0.13 c	0.00	15.08 a
Significance level					
Pr>F					
Treatment	0.0061	0.0202	0.0246	0.4027	0.0211
Contrast					
Control vs TDZ-oil	0.0069	0.1283	0.1747	0.2197	0.2981
Lift 3% vs Lift 5%	0.4916	0.5057	0.4262	0.6483	0.0005
TDZ-oil time linear	0.0016	0.0009	0.0009	0.0959	0.7188
TDZ-oil time quadratic	0.6128	0.3778	0.6846	0.6943	0.7752

^x Stem-end russet, 1 to 12 (12 = severe); retiform russeting, 1 to 11 (11 = severe)

^y Early = 28 Aug, optimum = 4 Sep, late = 15 Sep

^z Means within each column with the same letter are not significantly different at $p \leq 0.05$.

n.s. = No significant differences

Table 4. Effect of rates and timing of TDZ-oil (Lift[®]) application on fruit set and hand thinning intensity required of ‘Granny Smith’ (Experiment 1).

Treatment	Fruit set (Number of fruits/100 clusters)	Hand-thinning intensity (fruitlets/cm ² TCSA) ^w	Average yield per tree (kg)	Yield efficiency (kg · cm ⁻² TCSA)	Return bloom (%)
Control	59 n.s. ^y	0.1809 n.s.	85.34 ab (75.9) ^z	0.2879 n.s.	14.9 n.s.
3% TDZ-oil early ^x	46	0.1979	99.97 a (88.9)	0.3032	13.9
3% TDZ-oil optimum	53	0.2465	88.89 ab (79.0)	0.3261	21.4
3% TDZ-oil late	60	0.2295	88.52 ab (78.7)	0.3070	13.9
5% TDZ-oil early	48	0.1694	58.24 b (51.8)	0.2171	13.6
5% TDZ-oil optimum	58	0.2662	93.45 a (83.1)	0.2656	18.6
5% TDZ-oil late	35	0.2607	72.88 ab (64.8)	0.2080	16.9
Significance level					
(Pr>F)					
Treatment	0.6414	0.6599	0.1760	0.3016	0.1723
Contrast					
Control vs TDZ-oil	0.4226	0.3545	0.8900	0.7073	0.7327
TDZ-oil 3% vs 5%	0.5178	0.8466	0.0597	0.0179	0.9395
TDZ-oil time Linear	0.9473	0.2494	0.9950	0.8451	0.7164
TDZ-oil time quadratic	0.3858	0.2401	0.2473	0.3099	0.0094

^w TCSA = trunk cross sectional area

^x Early = 4 Sep, optimum = 15 Sep, late = 22 Sep

^y n.s. = No significant differences

Means within each column with the same letter are not significantly different at $p \leq 0.05$.

^z Estimated yield in ton·ha⁻¹, in brackets.

Table 5. Effect of rates and timing of TDZ-oil (Lift®) application on fruit size and number of seed per fruit of ‘Granny Smith’ apples (Experiment 1).

Treatment	Fruit diameter (mm)	Fruit length (mm)	Fruit length: diameter ratio	Fruit mass (g)	Number of seeds per fruit
Control	70.0 a ^z	63.1 a	0.902 ab	154.4 a	6.29 n.s.
3% TDZ-oil early ^x	67.2 b	59.9 bc	0.891 bc	137.0 bc	6.43
3% TDZ-oil optimum	70.0 a	62.7 a	0.896 ab	152.6 ab	6.78
3% TDZ-oil late	70.9 a	63.5 a	0.895 ab	157.2 a	6.52
5% TDZ-oil early	67.0 b	59.0 c	0.880 c	133.0 c	6.91
5% TDZ-oil optimum	68.6 ab	61.3 abc	0.893 ab	142.8 abc	6.64
5% TDZ-oil late	68.9 ab	62.3 ab	0.904 a	146.0 abc	6.83
Significance level (Pr>F)					
Treatment	0.0363	0.0052	0.0055	0.0274	0.1004
Contrast					
Control vs TDZ-oil	0.0056	0.0962	0.0684	0.1197	0.0311
TDZ-oil 3% vs 5%	0.1338	0.1207	0.6268	0.0774	0.1141
TDZ-oil time Linear	0.0065	0.0006	0.0021	0.0070	0.9974
TDZ-oil time quadratic	0.1848	0.1263	0.3790	0.2167	0.7930

^y Early = 4 Sep, optimum = 15 Sep, late = 22 Sep

^z Means within each column with the same letter are not significantly different at $p \leq 0.05$.

n.s. = No significant differences

Table 6. Effect of rates and timing of TDZ-oil (Lift®) application on fruit quality of ‘Granny Smith’ apples (Experiment 1).

Treatment	Stem-end russet score ^x	Fruit score >8 (%)	Malformed calyx cavity (%)
Control	0.60 n.s. ^z	0.22 n.s.	0.67 a
3% TDZ-oil early ^x	0.53	0.00	0.96 a
3% TDZ-oil optimum	0.67	0.00	0.24 a
3% TDZ-oil late	0.63	0.22	1.15 a
5% TDZ-oil early	0.41	0.00	1.55 a
5% TDZ-oil optimum	0.64	0.00	0.92 a
5% TDZ-oil late	0.55	0.00	8.53 b
Significance level (Pr>F)			
Treatment	0.2270	0.5607	0.0001
Contrast			
Control vs TDZ-oil	0.7254	0.1584	0.0739
TDZ-oil 3% vs 5%	0.2117	0.4525	0.0019
TDZ-oil time Linear	0.1810	0.3279	0.0002
TDZ-oil time quadratic	0.0375	0.6813	0.0164

^x Stem-end russet, 1 to 12 (12 = severe); no retiform russetting was detected

^y Early = 4 Sep, optimum = 15 Sep, late = 22 Sep

^z n.s. = No significant differences

Means within each column with the same letter are not significantly different at $p \leq 0.05$.

Table 7. Effect of TDZ-oil spraying time and chemical thinning interaction on fruit set of 'Golden Delicious' (Experiment 2).

Treatment		Fruit set (fruits/100 clusters)	
TDZ-oil time	Thinning		
Early ^x	Control	244	ab ^z
Early	BA+GA ₄₊₇ and NAD ^y	164	c
Early	NAA and BA	209	bc
Optimum	Control	207	bc
Optimum	BA+GA ₄₊₇ and NAD	184	bc
Optimum	NAA and BA	197	bc
Late	Control	305	a
Late	BA+GA ₄₊₇ and NAD	56	d
Late	NAA and BA	193	bc
<u>Significance level (Pr>F)</u>			
TDZ-oil time		0.6459	
Thinning		0.0001	
TDZ-oil time*Thinning		0.0022	

^x Early (28 Aug), optimum (4 Sep), late (15 Sep)

^y BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg, BA 100 mg

^z Means with the same letter are not significantly different at $p \leq 0.05$.

Table 8. Effect of TDZ-oil spraying time and chemical thinning combinations on hand thinning intensity, yield and return bloom of 'Golden Delicious' (Experiment 2).

Treatment	Fruitlets hand thinned (No · cm ⁻² TCSA) ^w	Yield		Return bloom (%)	
		Average yield per tree (kg)	Yield efficiency (kg · cm ⁻² TCSA)		
<u>TDZ-oil time</u>					
Early ^x	3.19 b ^y	26.02 ab	(38.5) ^z	0.3835 a	23.2 a
Optimum	4.14 a	28.03 a	(41.5)	0.4284 a	30.3 b
Late	2.78 b	22.00 b	(32.6)	0.2970 b	45.3 c
<u>Thinning</u>					
Control	4.19 a	25.05 n.s.	(37.1)	0.3896 n.s.	25.4 c
BA+GA ₄₊₇ and NAD ^x	2.48 c	23.40	(34.7)	0.3318	40.1 a
NAA and BA	3.45 b	27.60	(40.9)	0.3876	33.2 b
<u>Significance level (Pr>F)</u>					
TDZ-oil time	0.0003	0.0854		0.0089	0.0001
Thinning	<0.0001	0.3042		0.3017	0.0001
TDZ-oil time*Thinning	0.3170	0.8110		0.6910	0.5672

^w TCSA = trunk cross sectional area

^x Early = 28 Aug, optimum = 4 Sep, late = 15 Sep; BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg, BA 100 mg

^y Means within each column with the same letter are not significantly different at $p \leq 0.05$.

n.s. No significant difference

^z Estimated yield in ton·ha⁻¹, in brackets.

Table 9. Effect of TDZ-oil time application and chemical thinning combinations on fruit size and maturity of 'Golden Delicious' (Experiment 2).

Treatment	Fruit diameter (mm)	Fruit length (mm)	Fruit length: diameter ratio	Fruit mass (g)	Number of seeds per fruit
<u>TDZ-oil time</u>					
Early ^y	69.37 a ^z	64.16 a	0.925 a	147.9 a	7.70 a
Optimum	67.95 b	62.78 b	0.924 a	140.2 b	7.90 a
Late	68.21 b	63.46 ab	0.930 a	142.0 ab	7.28 b
<u>Thinning</u>					
Control	66.32 b	60.96 b	0.919 b	129.6 b	7.82 a
BA+GA ₄₊₇ and NAD ^y	69.47 a	65.05 a	0.937 a	150.3 a	7.45 b
NAA and BA	69.74 a	64.38 a	0.923 b	150.3 a	7.61 ab
<u>Significance level (Pr>F)</u>					
TDZ-oil time	0.0275	0.0811	0.2336	0.0551	0.0001
Thinning	0.0001	0.0001	0.0001	0.0001	0.0229
TDZ-oil time*Thinning	0.8516	0.6558	0.0769	0.6447	0.0815

^y Early = 28 Aug, optimum = 4 Sep, late = 15 Sep; BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg, BA 100 mg

^z Means within each column with the same letter are not significantly different at $p \leq 0.05$.

n.s. No significant difference

Table 10. Effect of TDZ-oil time application and chemical thinning combinations on fruit maturity and quality 'Golden Delicious' (Experiment 2).

Treatment	Starch breakdown at harvest (%)	Stem-end russeting ^x		Retiform russeting ^x	
		Average score	Score >8 (%)	Average score	Score >4 (%)
<u>TDZ-oil time</u>					
Early ^y	17.2 a ^z	3.38 a	3.45 n.s.	0.40 a	1.45 n.s.
Optimum	14.2 ab	2.95 b	2.10	0.29 ab	0.89
Late	11.1 b	3.15 ab	2.85	0.26 b	1.04
<u>Thinning</u>					
Control	13.2 n.s.	3.09 ab	2.52 n.s.	0.26 b	0.39 a
BA+GA ₄₊₇ and NAD ^y	14.7	2.98 b	2.47	0.19 b	0.42 a
NAA and BA	14.6	3.41 a	3.41	0.49 a	2.57 b
<u>Significance level (Pr>F)</u>					
TDZ-oil time	0.0016	0.0548	0.4354	0.1091	0.6548
Thinning	0.5742	0.0442	0.6020	0.0001	0.0008
TDZ-oil time*Thinning	0.7734	0.5684	0.8057	0.6188	0.8670

^x Stem-end russet, 1 to 12 (12 = severe); retiform russeting, 1 to 11 (11 = severe)

^y BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg, BA 100 mg

^z Means within each column with the same letter are not significantly different at $p \leq 0.05$.

n.s. No significant difference

Table 11. Effect of TDZ-oil spraying time and chemical thinning interaction on the presence of malformed calyx cavity of 'Golden Delicious' (Experiment 2).

Treatments		Malformed calyx cavity (%)	
TDZ-oil time	Thinning		
Early ^y	Control	6.96	d ^z
Early	BA+GA ₄₊₇ and NAD ^y	58.05	b
Early	NAA and BA	15.58	d
Optimum	Control	13.67	d
Optimum	BA+GA ₄₊₇ and NAD	62.76	b
Optimum	NAA and BA	27.91	c
Late	Control	8.68	d
Late	BA+GA ₄₊₇ and NAD	80.13	a
Late	NAA and BA	39.77	c
<u>Significance level (Pr>F)</u>			
TDZ-oil time		0.0001	
Thinning		0.0001	
TDZ-oil time*Thinning		0.0152	

^y Early (28 Aug), optimum (4 Sep), late (15 Sep); ^z BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg, BA 100 mg

^z Means with the same letter are not significantly different at $p \leq 0.05$.

Table 12. Effect of TDZ-oil spraying time and chemical thinning combinations on fruit set, hand thinning intensity, yield and return bloom of 'Royal Gala' (Experiment 2).

Treatment	Fruit set (fruits/100 clusters)	Fruitlets hand thinned (No · cm ⁻² TCSA) ^w	Yield		Return bloom (%)	
			Average yield per tree (kg)	Yield efficiency (kg · cm ⁻² TCSA)		
<u>TDZ-oil time</u>						
Early ^x	59 n.s. ^y	2.174 b	24.8 n.s.	(36.7) ^z	0.43 n.s.	26.5 b
Optimum	65	2.825 a	26.5	(39.2)	0.47	28.8 b
Late	62	2.417 ab	24.5	(36.3)	0.44	35.8 a
<u>Thinning</u>						
Control	94 a	3.393 a	30.6 a	(45.3)	0.51 a	25.5 b
BA+GA ₄₊₇ and NAD ^x	27 c	1.264 c	17.9 b	(26.5)	0.32 b	37.2 a
NAA and BA	65 b	2.759 b	27.4 a	(40.6)	0.52 a	28.4 b
<u>Significance level (Pr>F)</u>						
TDZ-oil time	0.7229	0.0365	0.5991		0.4939	0.0011
Thinning	0.0001	<0.0001	0.0001		<0.0001	0.0001
TDZ-oil time*Thinning	0.6200	0.2490	0.9475		0.3321	0.1771

^w TCSA = trunk cross sectional area

^x Early = 28 Aug, optimum = 4 Sep, late = 15 Sep; BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg, BA 100 mg

^y n.s. No significant difference. Means within each column with the same letter are not significantly different at $p \leq 0.05$.

^z Estimated yield in ton·ha⁻¹, in brackets.

Table 13. Effect of TDZ-oil time application and chemical thinning interaction on fruit size 'Royal Gala' (Experiment 2).

Treatments		Fruit diameter (mm)	Fruit length (mm)	Fruit mass (g)
TDZ-oil time	Thinning treatment			
Early ^y	Control	62.11 ef ^z	55.91 de	110.98 ef
Early	BA+GA ₄₊₇ and NAD ^y	64.50 bc	58.99 ab	125.65 bc
Early	NAA and BA	63.59 cd	58.00 bc	118.84 cd
Optimum	Control	60.99 f	54.65 ef	103.92 fg
Optimum	BA+GA ₄₊₇ and NAD	66.13 a	60.47 a	135.28 a
Optimum	NAA and BA	62.93 de	56.80 cd	114.71 de
Late	Control	61.05 f	53.92 f	102.84 g
Late	BA+GA ₄₊₇ and NAD	65.23 ab	59.23 ab	129.10 ab
Late	NAA and BA	64.22 bcd	57.40 cd	121.17 cd
<u>Significance level (Pr>F)</u>				
TDZ-oil time		0.9310	0.2345	0.9399
Thinning		0.0001	0.0001	0.0001
TDZ-oil time*Thinning		0.0242	0.0534	0.0121

^y Early = 28 Aug, optimum = 4 Sep, late = 15 Sep; BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg, BA100 mg

^z Means within each column with the same letter are not significantly different at $p \leq 0.05$.

Table 14. Effect of TDZ-oil time application and chemical thinning combination on fruit quality 'Royal Gala' (Experiment 2).

Treatment	Fruit Length: diameter ratio	Number of seeds	Stem-end russeting ^w		Fruit colour ^x		Malformed calyx cavity (%)	
			Average score	Score >8 (%)	Ground colour (1-5)	Foreground colour (1-12)		
<u>TDZ-oil time</u>								
Early ^y	0.909 a ^z	5.88 b	2.29 a	0.11 n.s	3.78 a	4.40 a	1.31 a	
Optimum	0.904 a	6.02 b	2.03 b	0.11	3.70 b	4.62 ab	0.66 a	
Late	0.895 b	6.74 a	2.07 b	0.31	3.68 b	5.09 b	0.64 a	
<u>Thinning</u>								
Control	0.893 c	6.40 a	2.09 a	0.19	3.66 b	5.28 a	0.40 b	
BA+GA ₄₊₇ and NAD ^y	0.912 a	6.13 b	2.07 a	0.18	3.80 a	4.06 b	1.77 a	
NAA and BA	0.903 b	6.11 b	2.23 a	0.15	3.70 b	4.79 a	0.45 b	
<u>Significance level (Pr>F)</u>								
TDZ-oil time		0.0004	0.0001	0.0078	0.2130	0.0012	0.0234	0.3662
Thinning		<0.0001	0.0428	0.1228	0.9548	0.0001	0.0001	0.0190
TDZ-oil time*Thinning		0.5917	0.3044	0.9780	0.8506	0.6258	0.5750	0.9428

^w Stem-end russet, 1 to 12 (12 = severe); retiform russeting, 1 to 11 (11 = severe)

^x Ground colour graded on chart from 1 (green) to 5 (yellow); foreground colour 1-12 (1 = full red)

^y Early = 28 Aug, optimum = 4 Sep, late = 15 Sep; BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg, BA100 mg

^z Means within each column with the same letter are not significantly different at $p \leq 0.05$. n.s. No significant differences

Table 15. Effect of different rates of TDZ-oil and different chemical thinning treatments on fruit set and hand thinning requirement of 'Golden Delicious' apples (Experiment 3).

Treatments	Fruit set (fruits/100 clusters)	Hand-thinned fruitlets (No · cm ⁻² TCSA) ^w	Yield	
			Average yield per tree (kg)	Efficiency (kg · cm ⁻² TCSA)
TDZ-oil - chemical thinning ^x				
3% 1) Control	223 a ^y	3.43 b	33.3 abc (49.3) ^z	0.517 ab
3% 2) BA+GA ₄₊₇	176 abc	3.41 b	39.4 a (58.3)	0.595 a
3% 3) BA+GA ₄₊₇ - NAD	102 e	1.57 cd	36.8 ab (54.6)	0.508 ab
3% 4) BA+GA ₄₊₇ and NAD	115 de	1.19 d	32.0 abc (47.3)	0.393 dc
3% 5) BA+GA ₄₊₇ - NAA	108 e	1.40 cd	28.3 c (42.0)	0.375 d
5% 1) Control	216 ab	4.33 a	36.4 ab (54.0)	0.548 a
5% 2) BA+GA ₄₊₇	171 bc	3.49 b	32.9 abc (48.7)	0.496 abc
5% 3) BA+GA ₄₊₇ - NAD	105 e	1.76 cd	30.8 bc (45.7)	0.428 bcd
5% 4) BA+GA ₄₊₇ and NAD	92 e	1.61 cd	27.9 c (41.3)	0.399 cd
5% 5) BA+GA ₄₊₇ - NAA	160 cd	2.03 c	30.2 bc (44.7)	0.3790 d
<u>Significance (Pr>F)</u>				
Treatment	0.0001	<0.0001	0.0889	0.0002
TDZ-oil 3% vs 5%	0.7343	0.0132	0.2012	0.2559
Control vs Thinning	0.0001	<0.0001	0.2535	0.0056

^w TCSA = trunk cross sectional area^x BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg. Each treatment from 2 to 5 received a second application of BA+GA₄₊₇ two weeks after the first one^y Means within each column with the same letter are not significantly different at p ≤ 0.05^z Estimated yield in ton·ha⁻¹, in brackets.

Table 16. Effect of different rates of TDZ-oil and different chemical thinning treatments on fruit size of 'Golden Delicious' apples at harvest (Experiment 3).

Treatments	Fruit diameter (mm)	Fruit length (mm)	Fruit length:diameter ratio	Fruit mass (g)
3% 1) Control	64.4 cd ^z	61.0 de	0.947 d	127.4 edf
3% 2) BA+GA ₄₊₇	62.9 ed	61.8 cd	0.982 a	119.7 ef
3% 3) BA+GA ₄₊₇ - NAD	65.8 abc	63.1 abcd	0.960 bcd	131.5 bcd
3% 4) BA+GA ₄₊₇ and NAD	67.3 a	65.0 a	0.967 abcd	141.8 a
3% 5) BA+GA ₄₊₇ - NAA	66.0 abc	64.0 ab	0.970 abc	135.0 abc
5% 1) Control	62.4 e	59.1 e	0.948 d	113.0 f
5% 2) BA+GA ₄₊₇	64.5 cd	63.2 abc	0.981 ab	127.4 cde
5% 3) BA+GA ₄₊₇ - NAD	64.7 bc	62.7 bcd	0.968 abcd	129.4 cde
5% 4) BA+GA ₄₊₇ and NAD	66.3 ab	63.4 abc	0.956 cd	136.7 abc
5% 5) BA+GA ₄₊₇ - NAA ₇	66.6 a	65.2 a	0.979 ab	140.7 ab
<u>Significance (Pr>F)</u>				
Treatment	<0.0001	<0.0001	<0.0045	<0.0001
TDZ-oil 3% vs 5%	0.3204	0.5970	0.8131	0.7961
Control vs Thinning	0.0001	0.0001	0.0002	0.0001

^y BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg. Each treatment from 2 to 5, received a second application of BA+GA₄₊₇ two weeks after the first one^z Means within each column with the same letter are not significantly different at p ≤ 0.05.

Table 17. Effect of different rates of TDZ-oil and chemical thinning treatments on fruit quality and incidence of malformation on fruitlets of 'Golden Delicious' apples at harvest (Experiment 3).

Treatments	Number of seeds/fruit	Stem-end russetting score >8 (%) ^x	Retiform russetting score >4 (%) ^x	Malformed fruit calyx cavity (%)
TDZ-oil - chemical thinning ^y				
3% 1) Control	6.47 ab ^z	2.96 a	5.50 b	0.67 d
3% 2) BA+GA ₄₊₇	6.23 bc	2.62 ab	4.98 b	3.08 cd
3% 3) BA+GA ₄₊₇ - NAD	5.90 bcd	0.28 c	8.16 ab	11.47 abc
3% 4) BA+GA ₄₊₇ and NAD	5.45 de	1.07 abc	5.08 b	21.05 a
3% 5) BA+GA ₄₊₇ - NAA	6.37 abc	0.71 bc	7.81 ab	15.59 ab
5% 1) Control	6.93 a	2.41 ab	9.40 ab	0.00 d
5% 2) BA+GA ₄₊₇	6.27 bc	2.25 abc	8.26 ab	9.74 bcd
5% 3) BA+GA ₄₊₇ - NAD	5.13 e	0.94 abc	15.23 a	15.43 ab
5% 4) BA+GA ₄₊₇ and NAD	5.75 cde	1.50 abc	15.02 a	19.00 ab
5% 5) BA+GA ₄₊₇ - NAA	6.39 ab	1.18 abc	7.45 b	16.02 ab
Significance (Pr>F)				
Treatment	0.0001	0.1755	0.0567	0.0002
TDZ-oil 3% vs 5%	0.9440	0.7879	0.0057	0.4812
Control vs Thinning	0.0001	0.0237	0.4620	0.0001
sLSD (5%)	0.63	2.11	7.46	10.48

^x Stem-end russet, 1 to 12 (12 = severe); retiform russetting, 1 to 11 (11 = severe); ground colour graded on chart from 1 (green) to 5 (yellow)

^y BA+GA₄₊₇ 46.8 mg, NAD 70 mg, NAA 9.9 mg. Each treatment from 2 to 5, received a second application of BA+GA₄₊₇ two weeks after the first one

^z Means within each column with the same letter are not significantly different at $p \leq 0.05$.



Figure 1. Fruit calyx cavity malformation on 'Golden Delicious' apples, detected at harvest.

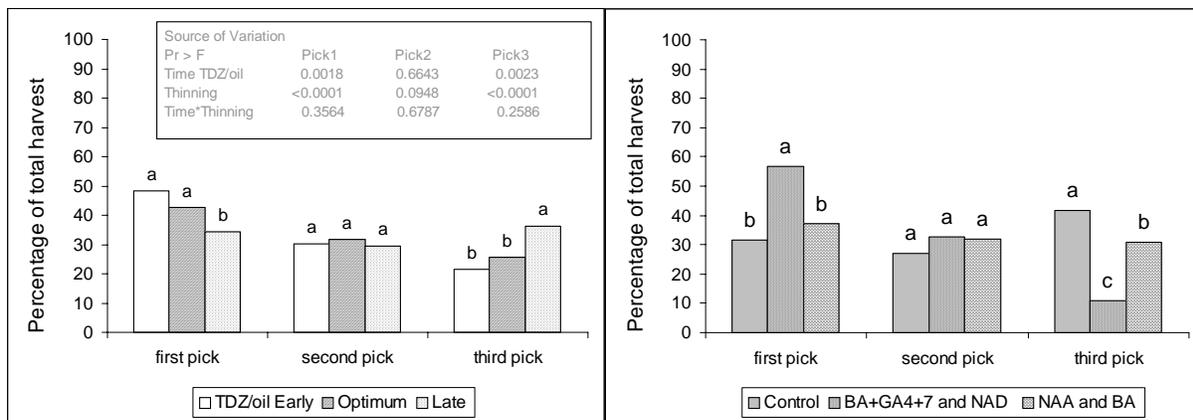


Figure 2. Effect of TDZ-oil spraying time (left) and chemical thinning (right) on harvest distribution in 'Royal Gala'. Season 2003-2004 (Experiment 2).

GENERAL CONCLUSIONS

Rest-breaking treatments are necessary to compensate for lack of adequate winter chilling and to compress flowering periods, although this last effect is not always evident when the spring is warm.

Hydrogen cyanamide (HC) appears to be a very effective rest breaking treatment in increasing bud burst in all concentration evaluated (0.245% HC + 4% oil and 0.98% HC + 4% oil in 'Royal Gala' and 0.98% HC + 4% oil and 1.96% HC + 4% oil in 'Golden Delicious'). Thidiazuron in combination with oil (TDZ-oil) was very effective for increasing bud burst and for concentrating flowering at the evaluated rates (3% and 5% for 'Royal Gala' and 4% and 6% for 'Golden Delicious'). Symptoms of phytotoxicity were observed at high rates of hydrogen cyanamide (HC) in both cultivars, and fruit deformation was induced by TDZ-oil applications in 'Golden Delicious'.

In relation to HC reduction with increasing oil concentration, it could be determined that no synergistic (or antagonistic) effects on budburst and yield were observed when mineral oil and hydrogen cyanamide were combined at different concentrations. The combination of mineral oil and HC is an effective rest-breaking treatment for 'Golden Delicious' apple trees. HC should not be replaced by mineral oil on its own. Mineral oil at 1 to 4% plus HC at 0.98% is able to break dormancy without reducing yield or negatively affecting fruit quality. HC at 1.96% reduced fruit set and yield. The improved budburst resulted in an increased number of spurs and dramatically improved the yield in the following season.

The used treatments of HC in combinations with oil and the mixture of TDZ and oil synchronised flowering on the tree and between 'Golden Delicious' and 'Royal Gala', which frequently are used to cross pollinate each other. In general, 0.245% HC + 4% oil is less effective than 0.49% HC + 4% oil in increasing bud burst in 'Royal Gala' apples. However, the higher rate may delay bud burst in some years due to phytotoxic effect of HC when buds are in a more advance stage of development. 'Golden Delicious' both 0.49% HC + 4% oil and 0.98% HC + 4% oil were able to improved bud break in 2001 and 2003, but not in 2002. Both treatments were effective in compressing and synchronising flowering in 2001, but late application can induce phytotoxicity. TDZ-oil was very effective for increasing bud burst, and also effective at 5% for concentrating flowering in 'Royal Gala' in 2002 and 2003. However, it appears that after a cooler winter, 6% TDZ-oil could result in an exacerbated bud burst effect with excessive vegetative growth, as was observed in 2002 for 'Golden Delicious'.

The combination of TDZ plus oil was also effective in increasing budburst. However, the effect on fruit set and yield was variable. Yield could possibly be increased by TDZ-oil applications. Return bloom the following spring was reduced, when applied at 5% in 'Royal Gala'. Malformation of the calyx cavity appears to be the main problem of this cytokinin-like compound in 'Golden Delicious' apples when applied as a rest breaking treatment. Hence, the time of application is crucial and an optimal time has to be established according to some quantitative or qualitative parameters. On the other hand, high rates of HC, namely 0.49% + 4% oil for 'Royal Gala' and 0.98% for 'Golden Delicious' in a mix with oil at 4%, reduce fruit set especially when the applications are late and the spring warm. In a mild winter or when a warm spring is forecast, and a certain amount of chilling has been satisfied, it is better not to wait for more CU accumulation during late winter, but rather to apply the rest-breaking treatment to avoid damage of the reproductive buds, and to ensure effectiveness on advancing and compressing the bud burst.

Malformation of the calyx cavity after TDZ-oil applications appears to be the main problem of this cytokinin-like compound in 'Golden Delicious' apples when applied as a rest breaking treatment, especially in late applications. The rate and time of TDZ-oil application, when applied as a rest-breaking treatment, influence the reproductive development of apples and hence fruit quality. Increased fruit set, the number of seeds, and reduced fruit russetting appear as beneficial results of TDZ-oil on its own; but are dependent on the cultivar, application rate, and time of application. TDZ-oil when applied late and at increasing rates increases the malformation of calyx cavities, especially when chemical thinning is performed using cytokinin-like compounds, such as BA alone or in a mixture with gibberellins (BA+GA₄₊₇), NAA and NAD. The effect seems to be cultivar specific, with 'Golden Delicious' most severely affected. Increased return bloom from late TDZ application appears to be beneficial, although it is also highly dependent on the cultivar and application time and rate.

TDZ-oil as rest-breaking treatment appears to be an option for dormancy release and increased bud burst. However, increased vegetative growth from early in the season can be a detrimental effect for fruit production and vegetative-reproductive balance. Research needs to be done in this regards. Apple trees tend to alternate bearing, with variable intensity depending on the cultivar, therefore the results cannot be extrapolated from one cultivar to another. In this regard, HC plus oil treatments increased also bud burst but may reduce fruit set depending on the cultivar, rate and timing of applications, therefore also may be affecting the tree development. Studies need to be done in tree architecture and alternate bearing effects.

The reduction in fruit set of HC + oil treatments needs to be studied in terms of phytotoxic effects not only on flower development, but also in pollination and ovule fertilization processes. Also TDZ-oil effects on flower fertility has to be investigated.

Rest-breaking treatments can compensate for lack of chilling and lead to production of temperate-zone fruit in warm climates, but the interaction with other practices used in fruit production has to be taken into account, particularly chemical thinning which is an important practice to increase fruit size and prevent alternated bearing. The chemicals used for both practices may interact not only in the synergetic or antagonist effects on flower development, but also in reproductive and vegetative bud development during the season. Advanced and compressed blossom may strongly affect chemical thinning, therefore also chemical thinning rates may need to be adjusted.