# The use of plant growth regulators to improve apple pedicel length and reduce fruit cracking

**By**

**Marno Wiehan van der Westhuizen**

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

Supervisor:

Prof. Karen I. Theron

Dept. of Horticultural Science

University of Stellenbosch

Co-supervisor:

Prof. Wiehann J. Steyn

Dept. of Horticultural Science

University of Stellenbosch

**March 2020**

# DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: March 2020

# ACKNOWLEDGEMENTS

Firstly, I would like to thank my heavenly Father for the strength and guidance He has given me throughout my studies.

Prof. Karen I. Theron, thank you for the support, guidance and expert advice over the two years. Your open-door policy, constructive criticism and continued interest in my study really helped me during my post-graduate years. You are truly a great mentor whom I look up to.

Prof. Wiehann Steyn, thank you for your constructive criticism and expert inputs.

I want to thank Philagro SA for funding this project and Fruitways (Pty) Ltd for supplying me with a bursary and internship during this study.

To Keith Bradley and Angelique Pretorius, thank you for always being willing to share your valuable knowledge and experience during my internship.

To Marais and Geoff (Applegarth), Lance (Alafontana), Reece (Oak Valley Estate), Jandri (Vastrap) and Oom Toekels (Welgemeen), thank you for providing me with the necessary help and support during my trials.

To Gustav Lötze, thank you for your assistance during my trials. To the technical staff, Vona, Shenti, Michilla, André and Eben, thank you for all your help during the two years in the lab and field. Your laughs and conversations made the long hours so much more enjoyable.

My fellow MSc students, thank you for all your help and support during the two years. I am grateful that I could share so many memorable moments with such a great group of people. A special thanks to Neil, Natalie and Arnold for assisting in the lab and field during the busy times.

To my parents, Gerhard and Elna van der Westhuizen, thank you for giving me the opportunity to pursue my dream. Thank you for all the love and support and for always believing in me. To my sisters, Therien van der Westhuizen and Wilanie du Plessis, thank you for all the teasing, laughter and support during my studies. I am truly blessed with a great family.

A special thanks to Oom Carel and Tannie Sanette Strydom for all the love and support.

To my fiancé, Lhente Strydom, thank you for your unconditional love, support and encouragement over the past seven years. I am truly blessed to have you in my life.

# SUMMARY

Maintaining apple fruit quality is complex and factors such as short fruit pedicels and fruit cracking reduce quality. Fruit pedicels of certain cultivars in the Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) region are problematic as they tend to be short, stubby and rigid and cause losses pre- and post-harvest. Fruit pedicel dimensions also vary within trees, complicating the control of the problem.

Gibberellin $A_4$ and $A_7$ ($GA_{4+7}$) on its own and in combination with 6-benzyladenine (6-BA) were evaluated to improve the pedicel lengths of 'Nicoter', 'Fuji' and 'Cripps' Pink', without having significant side-effects on fruit set, yield, fruit quality and return bloom. We also evaluated the effect of three bearing shoot types (terminal on spur, short shoot and long shoot) on the inflorescence composition as well as the effect of the three shoot types and two flower positions in the inflorescence (king and lateral) on pedicel dimensions and flower, and subsequent fruit quality.

Gibberellins $A_{4+7}$ successfully increased the pedicel length of 'Nicoter', 'Fuji' and 'Cripps' Pink' apples when applied multiple times between tight cluster and full bloom. Although higher rates of $GA_{4+7}$ (100 and 200 $mg \cdot L^{-1}$) significantly increased the pedicel length, the lower rates (10 to 50 $mg \cdot L^{-1}$) gave fewer negative side-effects on fruit set, yield and return bloom. The recommended treatments to increase pedicel length are 50 $mg \cdot L^{-1}$ $GA_{4+7}$, applied twice, 10 $mg \cdot L^{-1}$ $GA_{4+7}$, applied four times, and 20 $mg \cdot L^{-1}$ $GA_{4+7}$, applied twice for 'Nicoter', 'Fuji' and 'Cripps' Pink', respectively. Regarding the variable pedicel dimensions, neither the flower position, nor the type of bearing shoot had strong effects on the pedicel size and further research is needed to identify the origin of the intra-plant variation in pedicel lengths.

Fruit cracking on 'Fuji' (pedicel-end) and 'Rosy Glow' (calyx-end) has become a problem in the Ceres region during the past few seasons. $GA_{4+7}$ on 'Fuji' and $GA_{4+7}$ + 6-BA on 'Fuji' and 'Rosy Glow' were thus applied at an early and later period during the cell division phase of fruit growth to reduce cracking without causing side-effects on fruit set, yield, fruit quality and return bloom. Unfortunately, due to specific weather conditions and adjustment of management practices, no cracking was observed in the two seasons, except for low levels of pedicel-end cracking on 'Fuji' after controlled atmosphere storage in the second season. The return bloom of 'Fuji' was, however, reduced by all the $GA_{4+7}$ and $GA_{4+7}$ + 6-BA rates (10, 20 and 40 $mg \cdot L^{-1}$) during the first season and decreased linearly with increasing rate of $GA_{4+7}$, applied seven, 14 and 21 days after full bloom (d.a.f.b). It also decreased linearly with

increasing rate of $GA_{4+7}$ + 6-BA, applied seven, 21 and 35 d.a.f.b. during both seasons. Higher rates of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA should thus be used with caution when considered for cracking control.

# OPSOMMING


**Die Gebruik van Plantgroeireguleerders om Appelstingellengtes te Verbeter en Vrugkrake te Verminder.**

Handhawing van appelvrugkwaliteit is kompleks en faktore soos kort vrugstingels en vrugkrake benadeel vrugkwaliteit. Stingels van sekere kultivars in die Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) produksiearea neig om kort, dik en rigied te wees wat lei tot voor- en na-oesverliese. Die stingelafmetings varieer ook binne bome wat die beheer van die probleem verder kompliseer.

Gibberellien $A_4$ en $A_7$ ($GA_{4+7}$), op sy eie, of in kombinasie met 6-bensieladenien (6-BA) was geëvalueer vir die vermoë om stingellengtes van ‘Nicoter’, ‘Fuji’ en ‘Cripps’ Pink’ te verleng sonder om enige negatiewe effekte op vrugset, opbrengs, vrugkwaliteit en opvolgblom te hê. Ons het ook die effek van drie loottipes (terminaal op spore, kort lote en lang lote) op die bloeiwyse samestelling bestudeer, sowel as die effek van die drie loottipes en twee blomposisies in die bloeiwyse (terminaal en lateraal) op stingelafmetings, en die kwaliteit van blomme en die daaropvolgende vrugte.

Opeenvolgende $GA_{4+7}$ toedienings het die stingels van ‘Nicoter’, ‘Fuji’ en ‘Cripps’ Pink’ suksesvol verleng wanneer dit tussen die katpoot en volblom stadiums toegedien is. Al het die hoë konsentrasies (100 en 200 $mg{\cdot}L^{-1}$)‘n aansienlike toename in die stingellengtes veroorsaak, is dit nie die aanbevole behandelings nie aangesien die laer konsentrasies minder negatiewe effekte gehad het op vrugset, opbrengs en opvolgblom. Die aanbevole behandelings om stingels te verleng vir ‘Nicoter’, ‘Fuji’ en ‘Cripps’ Pink’ is dus onderskeidelik 50 $mg{\cdot}L^{-1}$ $GA_{4+7}$ tweemaal toegedien, 10 $mg{\cdot}L^{-1}$ $GA_{4+7}$, viermaal toegedien, en 20 $mg{\cdot}L^{-1}$ $GA_{4+7}$ tweemaal toegedien. Met betrekking tot die varierende stingellengtes, het nóg die blomposisie, nóg die tipe loot beduidende effekte op stingelafmetings gehad. Verdere navorsing is dus nodig om die oorsprong van die intra-plant variasie in stingellengtes te identifiseer.

Vrugkrake op ‘Fuji’ (stingel-ent) en ‘Rosy Glow’ (kelk-ent) het die afgelope paar seisoene ŉ probleem geword in die Ceres area. Bespuitings van $GA_{4+7}$ op ‘Fuji’ en $GA_{4+7}$ + 6-BA op ‘Fuji’ en ‘Rosy Glow’ was dus geëvalueer tydens ŉ vroeë en latere stadium van die seldelingsfase van vruggroei om die krake te verminder, sonder om negatiewe effekte te hê op vrugset, opbrengs, vrugkwaliteit en opvolgblom. Weens spesifieke weerstoestande en aanpassings aan bestuurspraktyke het geen krake in beide seisoene ontwikkel nie, behalwe vir ŉ klein hoeveelheid stingel-ent krake op ‘Fuji’ na beheerde atmosfeer opberging in die tweede

seisoen. Die opvolgblom van 'Fuji' was egter verminder deur al die $GA_{4+7}$ en $GA_{4+7}$ + 6-BA konsentrasies (10, 20 en 40 $mg{\cdot}L^{-1}$) gedurende die eerste seisoen en het liniêr afgeneem met toenemende konsentrasie van $GA_{4+7}$ wat sewe, 14 en 21 dae na volblom toegedien is. Verder het die opvolgblom van 'Fuji' in beide seisoene ook liniêr afgeneem met toenemende konsentrasie van $GA_{4+7}$ + 6-BA wat sewe, 21 en 35 dae na volblom toegedien is. Hoë konsentrasies van $GA_{4+7}$ en $GA_{4+7}$ + 6-BA moet dus versigtig gebruik word wanneer dit oorweeg word om krake met hierdie plantgroeireguleerders te beheer.

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

# TABLE OF CONTENTS

# GENERAL INTRODUCTION

The South African apple industry is an important role player in both local and international apple markets. During the 2018 season, 197 689 tons of apples were sold locally, and 393 344 tons exported (Hortgro, 2018). Top quality fruit is very important to remain competitive and ensure continued growth in these markets. Maintaining high quality is, however, a complex process as fruit quality is influenced by several factors such as climate, orchard practices and fruit characteristics (De Jager and De Putter, 1999).

One such fruit characteristic is the apple pedicel as it contributes to the final fruit quality (Habdas et al., 1982; Prive et al., 1988). It connects the vegetative and reproductive parts of a tree and serves as a conduit for water, mineral, hormone and assimilate transport. In the Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) region of South Africa, the pedicels of certain cultivars e.g. Cripps' Pink, Nicoter and Fuji tend to be short, stubby and rigid. Such pedicels increase the density within apple clusters (botanically a cyme), which leads to bruising and dropping of neighboring apples during harvest. In addition, the rigid pedicels tear out at harvest or puncture apples that are being transported in picking bags and bins (S. Reynolds and J. Moelich, personal communication). Fruit quality and thus the quantity of marketable apples is thus reduced. Pedicels also vary within trees, complicating the control of the problem.

Another factor diminishing apple fruit quality is fruit cracking. This disorder became apparent in the Ceres region, the second biggest apple production region of South Africa (Hortgro, 2018), especially on 'Fuji' and 'Cripps' Pink'/ 'Rosy Glow' during the past few seasons. 'Rosy Glow' apples developed calyx-end ring cracks, as described by Stern et al. (2013), while 'Fuji' apples developed small, concentric cracks at the pedicel-end. The cracking is not only a major cosmetic defect, but also serves as an entrance to pathogens and give rise to moisture loss and shriveling that subsequently reduce the marketability, storage and shelf life (Goode et al., 1975).

The purpose of this study was to evaluate the efficacy of plant growth regulators, gibberellin $A_4$ and $A_7$ and 6-benzyladenine, known to promote cell enlargement and stimulate cell division, respectively (Al-Wir, 1978; Smith et al., 1996; Wismer et al., 1995), on apple pedicel elongation and apple cracking. In addition, the origin of the variable pedicel lengths is also investigated.

In the literature study we provide a broad overview of the anatomical development of apple fruit and the factors that influence it as well as the factors that cause fruit cracking, and methods to mitigate it.

In Paper 1 we report on the efficacy of different rates and timings of $GA_{4+7}$ and the combination of $GA_{4+7}$ and 6-BA, on apple pedicel elongation of apple cultivars Fuji, Nicoter and Cripps' Pink. In addition, we evaluate the effect on fruit set, yield, fruit quality and return bloom to determine whether side-effects occurred.

In Paper 2, we report on the effect of three shoot bearing types (terminal on spurs, short shoots and long shoots) and two flower positions in the inflorescence (king and lateral) on the inflorescence quality, flower pedicel dimensions, and subsequent fruit quality of apple cultivars Fuji, Nicoter and Cripps' Pink.

In Paper 3 we report on the efficacy of different rates and timings of $GA_{4+7}$ to reduce 'Fuji' cracking and $GA_{4+7}$ + 6-BA to reduce 'Fuji' and 'Rosy Glow' cracking. In addition, we evaluate the effect on fruit set, yield, fruit quality and return bloom to determine whether side-effects occurred.

## Literature Cited


Al-Wir, A.I. 1978. The influence of growth regulators on the anatomical, morphological, development and quality of apple fruits. Iowa State Univ., Ames, PhD Diss.

De Jager, A. and H. De Putter. 1999. Preharvest factors and postharvest quality decline of apples. Acta Hort. 485:103-110.

Goode, J.E., M.M. Fuller, and K.J. Hyrycz. 1975. Skin-cracking of Cox's Orange Pippin apples in relation to water stress. J. Hort. Sci. 50:265-269.

Habdas, H., L.S., Jankiewicz, and B. Borkowska. 1982. Changes in the anatomical structure of the apple fruitlet pedicels preceding June drop. Acta Agrobot. 35:11-23.

Hortgro, 2018. Key deciduous fruit statistics. www.hortgro.co.za

Prive, J.P., D.C. Elfving, and J.T.A. Proctor. 1988. Pedicel characteristics of four apple cultivars. Fruit Var. J. 45(4):122-125.

Smith, R.C., P.R. Matthews, P.H.D. Schunmann, and P.M. Chandler. 1996. The regulation of leaf elongation and xyloglucan endotransglycosylase by gibberellin in 'Himalaya' barley (*Hordeum vulgare* L.) J. Expt. Bot. 47(302):1395-1404.

Stern, R., R. Ben-Arie, and I. Ginzberg. 2013. Reducing the incidence of calyx cracking in 'Pink Lady' apple using a combination of cytokinin (6-benzyladenine) and gibberellins ($GA_{4+7}$). J. of Hort. Sci. and Biotechnol. 88(2):147–153.

Wismer, P.T., J.T.A. Proctor, and D.C. Elfving. 1995. Benzyladenine affects cell division and cell size during apple fruit thinning. J. Amer. Soc. Hort. Sci. 120(5):802-807.

# LITERATURE REVIEW: A Holistic View of Apple Fruit Cracking

**Table of contents**

# 1. Introduction

The development of an apple (*Malus domestica* Borkh.) fruit is a complex process consisting of several phases as flowers develop into edible fruit. The quality of the final fruit is determined throughout this developmental process, starting with the induction of flower buds (Faust, 1989). Therefore, in order to produce apples of high quality, all developmental phases need to proceed optimally.

These developmental processes are prone to be influenced by environmental or cultural factors, both beneficial and detrimental. One such example is the disorder fruit cracking. Several apple cultivars are susceptible to this disorder and major losses have been reported (Opara et al., 1997a). As the market price of apples are subject to certain quality standards, disorders like cracking which can affect both the external and internal quality are to be avoided.

The aim of this literature review is to provide a broad overview of the anatomical development of apple fruit and the factors that influence it as well as the factors that cause fruit cracking, and methods to mitigate it.

# 2. Structure of the apple fruit.

The development of an apple fruit involves several differentiation processes leading to the formation of new structures. It is therefore necessary to understand the different parts of an apple.

## 2.1 Core and cortex tissue.

An apple flower undergoes several changes before the fruit, consisting of a fleshy meso- and exocarp and a strong, membranous endocarp, develops (Zielinski, 1955). This fruit is divided into two parts that develop from different parts of the flower, i.e. the core that includes the carpellary tissue and the cortex that includes the flesh of the apple outside the core line (Pratt, 1988). The origin of this extracarpellary tissue is subject to two hypotheses: One stating that it originates from the flower receptacle (receptacular hypothesis) and the other that it originates from the fusion of floral appendages (appendicular hypothesis) (Esau, 1977).

The core line, which is essentially a sheet of parenchyma cells, serves as an indicator of the line where the carpellary tissue (the core) fuses with the extracarpellary tissue (the cortex) (Drazeta, 2002). The ovary inside this line is a syncarpous ovary since the gynoecium consist of five fused carpels. This ovary differentiates into the cartilaginous endocarp, which lines the five locules, each containing two to four ovules that will develop into seeds (Pratt, 1988).

The extracarpellary tissue is made up of parenchyma cells that can vary in size, shape and cell wall thickness, depending on where they are situated in the flesh. These cells have certain properties that influence the final texture of the apple tissue. Apart from the vacuolated nature of the mature cells, they also contain non-rigid cell walls to contribute to tissue strength by means of the internal turgor pressure (Harker et al., 1997). Structures that exist in both the cortical and carpellary tissue include the vascular bundles consisting of xylem and phloem (Kraus and Ralston, 1916).

## 2.2 Apple seed.

The apple seed is a vital part of the fruit with it being an important site of hormone production (Luckwill et al., 1969). An apple seed contains an embryo formed during the fertilisation process of the ovule. The embryo is initially surrounded by a nutrition source, the endosperm, which is consumed by the embryo during its developmental period. Due to the dicotyledonous nature of apples, seeds contain two cotyledons that store and provide energy during germination. Furthermore, the seed is enclosed by a hardened coating, the testa, which supplies the seed with biochemical and mechanical protection until germination (Hopkins and Hüner, 2009).

## 2.3 Apple peel.

The peel of the fruit serves as a multifunctional structure that protects the fruit against factors that can negatively affect the functional integrity (Bell, 1937). Such factors include mechanical damage, unfavorable environmental conditions and water loss. The multi-layered peel consists of a cuticle, epidermis and a hypodermis. Epidermal hairs or trichomes (modified epidermal cells) are present on the outside of the peel and provides protection to the young ovaries in developing flowers against dehydration. At full bloom these hairs get separated due to increased cell division in the other epidermal cells between them. Eventually the trichomes are replaced by the cuticle when the fruit reaches maturity, except for inside the cavities of the pedicel and calyx end of apples (Bell, 1937). The cuticle is a continuous wax-like layer on the epidermis, except over the stomata and young lenticels (Bell, 1937). This coating consists of two layers, the exterior, cuticle *sensu stricto,* and the cuticular internal layer. The outside layer comprises of pure cutin and wax molecules, whereas the inner layer consist of carbohydrates, waxes and cutin (Pratt, 1988). Bell (1937) found that the cuticle, initially as thin as 1-1.7 µm, reaches an average thickness of 23 µm and protrudes between the epidermal cells towards the hypodermal area. While this cuticle layer is of non-cellular nature, the epidermis and hypodermis are cellular layers (Miller, 1982). The thin walled epidermal cells of 'McIntosh Red' apples exhibit increased cell division until just past full bloom, after which the division stops. These cells consist of a greater radial measurement compared to tangential length until approximately one month after full bloom, when the ratio is reversed, and further growth is accompanied by an increase in tangential length. According to Bell (1937), the bi-layered hypodermal cells below the epidermis originate from the cortex parenchyma. These cells have the same shape and size as the neighboring cortex cells and can thus only be distinguished by their thicker walls and dense cellular contents at maturity.

### 2.4 Apple pedicel.

Another important part of the apple fruit is the stalk or pedicel. This structure not only plays an important role in the flow of water and nutrients between the fruit and the tree, but is also responsible for the attachment of the fruit (Kraus and Ralston, 1916). Although this structure proves to be of great importance, relatively little research has been done on the anatomical development of the apple fruit pedicel (Habdas et al., 1982). The elongation of the pedicel stops at full bloom, but the final diameter is only reached by three to four weeks after full bloom (Prive et al., 1988). Habdas et al. (1982) published a cross-section of the pedicel of the 'McIntosh' apple. The outer part of the pedicel consists of an epidermal layer, collenchyma tissue, cortex parenchyma and cortex sclereids. Beneath these cell layers are the vascular tissue and the pith cells, both lignified and with thin walls. Furthermore, they also showed differences in the pedicels of different fruitlets, where larger fruit experienced a more pronounced development of secondary xylem as well as the lignification of xylem parenchyma cells, pith cells, phloem fibers and cortex sclereids.

## 3. Anatomical development of apples from bud stage to fruit.

The development of an apple fruit is a complex process that has been the focus of several studies over the years. This process starts with certain components of a flower, contained within a mixed reproductive bud, that develops into a mature apple fruit after several growth phases

(Drazeta, 2002). Although cultivars may differ in terms of sensory attributes and ripening times, the anatomical development pattern among them is the same.

The first stage is the development of the apple reproductive bud. These buds are mixed, containing both reproductive and vegetative primordia (Hoover et al., 2004). The position of these buds can differ depending on the type of shoot it develops on. While the buds are borne in the terminal position on short shoots and spurs, long shoots may bear them terminally as well as laterally (Koutinas et al., 2010).

Due to the buds being mixed, a commitment is needed to initiate the reproductive primordia and continue with flower differentiation. Prior to this commitment, vegetative primordia within the bud are differentiated into nine to ten bud scales, two to three transitional leaves and five to six foliage leaves (Hoover et al., 2004). Thereafter the commitment proceeds through the processes of flower induction and initiation. The induction process precedes flower initiation as it entails a change on a hormonal/biochemical level that causes the meristem to start its reproductive development. After the internal shift from vegetative to reproductive has been made, flower initiation takes place. The initiation is known to be the first visible morphological change of the meristem (Hättasch et al., 2008), where the apical region of the meristem broadens, adopting a dome shape. The time that the dome-shaped meristem occurs differs among cultivars. Hoover et al. (2004) found that the doming process in 'Fuji' apples occurs at approximately 86 days after full bloom (d.a.f.b.) while in cultivars such as Royal Gala, Braeburn and Pacific Rose™ it happens between 104 and 112 d.a.f.b. Greybe (1997) also reported that the change in the meristem of 'Royal Gala' takes place during the second week of January. Bergh (1985a) found initiation in 'Starking' apples 76 to 84 d.a.f.b. Irrespective of these differences, flower initiation only occurs after shoot extension growth has been terminated (Abdulkadyrov et al., 1972).

Following the first sign of flower initiation, four to six lateral floral meristems and subtending bracts are initiated by the domed meristem (Foster et al., 2003). The differentiation of these meristems, however, only takes place after the sepals and bractlets of the terminal floral meristem are initiated. Bergh (1985a) found that in 'Starking' the terminal floral primordia are formed in the following order: Sepal primordia in early January, followed by the petal primordia, the first whorl of ten stamens and carpel primordia during the second week of February. All carpel primordia and the three whorls of stamens were present in the second week of March. Therefore, these developing flowers are hermaphroditic, containing male pollen producing stamens and female ovule producing pistils. The stamens consist of a filament and anther and the pistil/carpel includes a style and stigma (Drazeta, 2002).

While further development of the flower occurs at a slow rate during the winter, the rate picks up from bud swell and during bloom in spring (Bergh, 1985a). During the final stage of flower formation, the pollen grains develop from the pollen mother cells, undergoing meioses in the anther locules (Pacini and Franchi, 1988). Furthermore, megasporogenesis takes place where megaspores are formed through meioses of the megaspore mother cells in the anatropous ovules and megagametogenesis where embryo sacs form by mitotic division (Koltunow, 1993). The differentiation and timing of differentiation of the flower buds are influenced by the bearing position. Kozma et al. (2003) found that buds on older spur systems undergo differentiation first, where after the buds on the younger spur systems follow and then finally those on the longer shoots. According to Abdulkadyrov et al. (1972), the termination of growth is a prerequisite for flower initiation, therefore supporting Kozma et al. (2003) as spurs terminate extension growth before long shoots (Huet, 1973).

After the differentiation process is completed, flowers consist of five sepals, five petals, three whorls of stamens and five carpels. Both the number of flowers in mixed buds and the bearing position influence the time of flowering (Tromp et al., 1976). Mixed buds with six to seven flowers bloom earlier than clusters with fewer flowers. Flowering occurs first on spurs then on short shoots and lastly on the long shoots. Flowering and the quality of the subsequent fruit are also affected by the age of the bud and the presence of leaves within the inflorescence (Davis, 2002; Tromp, 1976). Mature buds tend to form flowers with good set potential. Although flower abscission can be high, these types of buds still produce enough good quality fruit. Buds that took longer to induce form fewer flowers with a weak set potential. These flowers produce average sized, elongated fruit with a long pedicel. Lastly, the old buds that were induced at the latest stage contain flowers that have a low set potential and fruit that set tend to be smaller with short pedicels. Regarding the leaves, Elsysy and Hirst (2017) found that removal of bourse leaves inhibits flower formation at the terminal position on the bourse shoot. This was attributed to a combination of three possibilities, viz. the reduction in carbohydrates, the reduced transpiration and thus lower supply of hormones via the xylem stream and the inhibition of the formation and transport of flowering signals.

The next step in fruit development takes place after anthesis and consists of two important processes, viz. pollination and fertilization. Pollination, when successful, leads to ovule fertilization and seed set, thus creating signals that will lead to fruit growth (Malladi and Johnson, 2011). These signals include a collaborative action of two growth hormones, auxin and gibberellin, which leads to fruit set and activation of cell division (Nitsch, 1970). The pollination process starts when the flowers open and the anthers split at a point of weakness in order to release the pollen grains (Jackson, 2003). Due to the self-incompatible nature of most commercial cultivars, self-fertilization with these 2-nucleate pollen grains is prevented (Drazeta, 2002; Janick et al., 1996; Shoemaker, 1926). Therefore, cross-pollination is required whether by hand, insect vectors or wind (Janick et al., 1996; Palmer-Jones and Clinch, 1966). The pollen grains are transported from the male-structure to the five stigma surfaces. Due to the extracellular secretions from the papilla cells, the stigmas of apple flowers are moist, which is important for the germination process of the pollen grains (Cresti et al., 1980; Sedgley, 1990). The moist environment on the stigmas causes the hydration of the pollen grains leading to germination. According to Pratt (1988), there are two barriers that control the germination process of pollen grains and the growth of pollen tubes. These barriers include the stigma-style-pollen interactions and transmitting tissue-pollen tube interactions. If the pollen is compatible, emergence and elongation of the pollen tube through the transmitting tissue of the style towards the ovule will follow (Jackson, 2003). When the elongation process of these tubes is finalized, it enters the ovule through the micropyle. Two generative nuclei are then released from the tubes in each ovule. While one nucleus fertilizes the egg cell in the ovary to form a diploid zygote, the other nucleus combines with two polar nuclei in the embryo sac, which forms a triploid nucleus and develops into the nuclear-free endosperm (Jackson, 2003). After fertilization, fruit growth follows a sigmoidal pattern consisting of three phases (Murneek, 1954; Tromp, 1976). Phase one entails exponential cell division that lasts until 35 to 45 d.a.f.b. (Bain and Robertson, 1951; Bollard, 1970; Tetley, 1930). The rapid cell division is accompanied by a twofold increase in cortical cell layers from full bloom until two weeks after full bloom (Tukey and Young, 1942). Bergh (1985b) also found that the maximum number of cortical cells in ‘Starking Delicious’ were formed 35 d.a.f.b. As cell division ceases, fruit grow by means of cell enlargement, i.e. phase two (Bain and Robertson, 1951). The conversion from division to enlargement occurs from the inside of the fruit, thus leading to a prolonged division period in the epidermal region (Bollard, 1970; Tromp et al., 1976). During the last stage of the sigmoidal pattern, the fruit reaches its final size through cell enlargement. Seed development occurs simultaneously with fruit growth. Shortly after fertilization, the nucellus tissues enlarge through cell division and elongation. Subsequently, the nucellus is digested by the developing endosperm. This triploid tissue is initially in a liquid form until the cell walls are formed three to four weeks after fertilization. At this time phase two of fruit growth is in progress and is accompanied by a decrease in the inner endosperm tissue which serves as a nutrition source for the developing embryo. During the last stage of fruit growth, the embryo, also following a sigmoidal growth pattern, reaches its dormant stage and the testa solidifies and turns brown (Tromp et al., 1976).

## 4. Factors that influence the anatomical development of apples

### 4.1 Cultural practices

#### 4.1.1 Effect of crop load

Crop load is defined as the number of fruit per tree (McArtney, 2011). Several researchers have found that the number of apples per tree have a significant effect on the final fruit size at harvest (Bound, 2001; De Salvador et al., 2006; Link, 2000). Trees bearing heavy crops deliver smaller fruit with lower weight compared to trees with a smaller crop load (Bergh, 1990a; De Salvador et al., 2006). This indicates the importance of managing the crop load, whether it is through mechanical or chemical thinning, to ensure fruit of optimal size.

Although the process of thinning has proved to be a viable option to control fruit number and therefore fruit size, it is important to understand the underlying mode of action in order to execute it properly. One of the main quality attributes of apples is final size and this is determined early in the developmental cycle. As the number of cells in the fruit primarily determines the potential final size (Bain and Robertson, 1951, Greybe, 1997; McArtney, 2011), the cell division period of apple growth serves as the target for fruit size manipulation. By thinning pre-bloom by means of removing flower buds, or thinning flowers and fruitlets at an early stage post-bloom, the number of fruit sinks is reduced (Bergh, 1990a). This decreases the competition among the remaining fruit for available carbohydrates and results in an increased rate of cell division (McArtney, 2011). Wünsche et al. (2000) found that trees with a lower crop load have fruit that reach maturity earlier and with increased firmness.

### 4.1.2 Effect of pruning

Pruning by heading or thinning shoots or removal of buds have different effects on tree or fruit development depending on when it is applied and at which severity. Pruning in the summer improves the distribution of light within a tree, but also reduces assimilate supply (Saure, 1987). One of the main advantages of summer pruning is the promotion of the red color on apples (Gardner et al., 1952; Ystaas, 1992). Fruit size is also affected as Ferree et al. (1984) found that summer pruning reduced fruit size due to the decreased assimilate supply (Bound and Summers, 2001). On the cellular level, Saure (1987) found that pruning at the end of summer did not affect cell number, but resulted in slightly smaller cells, thus reducing apple fruit size. It is important to note that the effect on fruit size is dependent on the carbohydrate supply following summer pruning (Li, 2001). Taylor and Ferree (1984) found that a reduction in the final yield by summer pruning resulted in an increase in the apple fruit size.

Summer pruning also increases the flower density in the following season by increasing the number of flowering spurs (Cain, 1971; Gardner et al., 1952). Taylor (1982) reported that summer pruning resulted in more flower buds on terminally located spurs in the subsequent season. Myers and Ferree (1984) however ascribed the increase in density to more flowers per cluster instead of more spurs.

Rom (1992) reported that a reduction in spur numbers reduces the competition among flowers for photosynthates and nutrients and thus enhances fruit growth. Bound and Summers (2001) found an increase in the length/diameter ratio of red 'Fuji' apples with increasing severity of winter pruning. They also reported that fruit quality is improved by winter pruning compared to summer pruning. Unfortunately, no details were given on the number and/or depth of cut thus making interpretation of results difficult.

### 4.1.3 Effect of irrigation

Irrigation play an important role in fruit development and the final fruit size. Naor et al. (1997) reported that certain irrigation regimes help maintain the turgor for cell expansion and subsequently fruit growth. When irrigation and precipitation are limited (drought circumstances), the availability of assimilates is reduced due to a lower stomatal conductance which leads to smaller fruit (Naor et al., 1995). According to Kilili et al. (1996), maintaining an optimum plant water status through irrigation is especially important between full bloom and 104 d.a.f.b. as they found a reduced fruit weight on ‘Braeburn’ apples when irrigation was withheld during that period.

### 4.1.4 Effect of endogenous plant hormones and plant growth regulators

Plant growth regulators (PGRs) were defined by Rademacher (2015) as "naturally occurring or synthetic compounds that affect developmental or metabolic processes in higher plants, mostly at low dosages". These compounds are used in the agricultural sector to manipulate the morphological structure, improve the harvesting process and -window, increase fruit quality and -yield, while minimizing the susceptibility of crops to certain stress factors (Rademacher, 2015). The effect that these important plant hormones, auxins, gibberellins, cytokinins, abscisic acid and ethylene (Petracek et al., 2003), have on the development of apples are discussed below.

*Auxin.* Auxin is an important phytohormone in apple fruit development due to its involvement in fertilization, fruit ripening and -abscission as well as cell division and -expansion. Devoghalaere et al. (2012) investigated the role of indole 3-acetic acid (IAA), the principal auxin in higher plants, in the control of fruit size in apples. They found that the free IAA concentration in the apple cortex increased during the cell expansion period. Subsequently, they investigated the effect of exogenous IAA during this period by injecting three concentrations in 'Royal Gala' apples at an early stage of development (30 d.a.f.b.). Two weeks after injection, the lower concentrations ($10^{-7}$ M and $10^{-5}$ M) led to a significant increase in fruit diameter compared to the control. This increase was due to larger cells. The highest concentration ($5.10^{-5}$ M), however, had an inhibiting effect on fruit growth. These findings concur with Trewavas and Cleland (1983) that different concentrations of auxin can lead to variable responses.

Apart from the direct effect IAA has on apple fruit size, synthetic auxins (naphthalene acetic acid (NAA) and naphthalene acetamide (NAD)) act as thinning agents, therefore indirectly enhancing fruit size (Petracek et al., 2003; Rademacher, 2015). NAA can be used to inhibit pre-harvest drop of certain cultivars like McIntosh (Rademacher, 2015). It is, however, not widely used by producers due to a double application that may be needed and the possible reduction on storage life of apples (Petracek et al., 2003).

*Gibberellins.* Gibberellin (GA) is an important hormone group with a wide variety of functions in horticultural crops. Endogenous GAs regulates both the normal bolting of plants, like stimulating longitudinal growth in higher plants, and seed germination as it contributes to the mobilizations of food reserves and activation of the embryo growth (Karssen et al., 1989; Taiz and Zeiger, 2002). It also affects processes such as flower initiation, sex determination and the transition from juvenile to the mature stage in some plants (Taiz et al., 2018). Spinach (long-day plant) for instance experience a five-fold increase in $GA_1$ when exposed to long days which subsequently promotes flowering (Taiz and Zeiger, 2018; Zeevaart, 1971). Although there are more than 130 known GAs to date, only gibberellin $A_3$ ($GA_3$), gibberellin $A_4$ ($GA_4$) and gibberellin $A_7$ ($GA_7$) are currently used commercially as PGRs (Rademacher, 2015). These PGRs are used to improve fruit set, fruit and shoot growth and reduce disorders like russeting. However, application can also cause a reduction in return bloom and formation of malformed fruit (Petracek et al., 2003). These effects are discussed in more detail below.

Gibberellins are vital in fruit set. Bukovac and Nakagawa (1967) investigated the efficacy of $GA_1$ to $GA_{10}$, $GA_{13}$ and $GA_{14}$ in inducing parthenocarpic fruit set in the European crab apple (*Malus sylvestris* Mill.) and found that $GA_4$ and $GA_7$ were the most effective. The fact that these two GAs are abundantly present in immature apple seeds (Dennis, 1967; Ramírez et al., 2001) supports the role of seed-produced GAs in fruit set.

Gibberellins also promote fruit growth by means of cell enlargement. Al-Wir (1978) confirmed the latter by treating 'Chieftain' apples with $GA_{4+7}$ and the cytokinin 6-benzyladenine (6-BA) at 50% petal fall. The growth during the first two weeks after the treatment entailed an increase in cell number, which was ascribed to the promotion of cell division by 6-BA. As all these apples had the same number of seeds, he concluded that the subsequent growth was due to the $GA_{4+7}$ effect on cell enlargement. Fruit shape can also be altered by endogenous GAs. According to Way (1995), apples develop asymmetrically when only some of the five flower stigmas are pollinated and subsequently only some locules contain seeds. As seeds are a rich source of GAs, this uneven spread can cause the formation of misshapen fruit (Drazeta et al., 2004). The mechanism by which this hormone contributes to cell expansion involves the stimulation of the enzyme xyloglucan endotransglycosylase. This enzyme hydrolyzes the xyloglucan structures within the cell walls, thereby promoting cell wall extension (Smith et al., 1996).

Detrimental consequences of GAs ($A_1$, $A_4$ and iso-$A_7$) include the inhibition of apple flower induction, which subsequently reduce the return bloom (Ramírez, 2001; Ramírez et al., 2004; Ramírez and Hoad, 1981). Both endogenous and exogenously applied GAs affect the flower formation (Greene, 1993; Ramírez, 1998), thus it is not regularly used to increase fruit set as it can lead to a good crop in the current season, but a subsequent decrease in flowers in the next season (Petracek et al., 2003).

*Cytokinins.* Cytokinin is a phytohormone that counteracts auxin during apical dominance, postpones leaf senescence due to the enhancement of chlorophyll synthesis and stimulates cell division and thus enhances fruit growth (Rademacher, 2015).

A cytokinin used in the apple industry is 6-benzyladenine (6-BA). This compound is used as a post-bloom chemical thinning agent on several apple cultivars (Bound et al., 1997). 6-BA, however, differs from other thinning agents as it not only improves the fruit size through the thinning action, which reduces competition for assimilates, but also by directly stimulating cell division (Wismer et al., 1995).

The mechanism by which this compound thins apples has been investigated by several researchers. Stopar et al. (2001) and Yuan and Greene (2000) found that 6-BA inhibits apple leaf photosynthesis, which subsequently leads to less assimilates for growing fruits. Benzyladenine also stimulates vegetative growth of apple trees, which increases competition for assimilates (Dal Cin et al., 2007). Dal Cin et al. (2007) investigated the abscission process after applying 6-benzylaminopurine (BAP), which is similar to 6-BA (Da Silva, 2012), and found that the production of ethylene increased in the fruit and leaves after application, thus stimulating abscission. The time of application of 6-BA for these thinning mechanisms differ among cultivars, but generally it performs optimally when applied when fruitlet diameter is 8-12 mm, roughly between 14 and 21 d.a.f.b. (Bound et al., 1997; Bubán, 2000). As 6-BA also affects fruit size by stimulating cell division, time of application is crucial. Wismer et al. (1995) found that 6-BA was most effective if applied at the period of maximum division, i.e. when fruit are approximately 8-12 mm in diameter. On an anatomical level, they discovered that the larger 'Empire' apples were due to an increase in the rate at which the cell layers of the cortex were formed. It is important to note that although 6-BA stimulated cell division, it did not have an impact on the duration of the division period. The ability of 6-BA to affect cell division directly when applied as a thinning agent has benefitted the apple industry as larger apples, with an increased number of smaller cells, maintain top quality grade longer throughout cold storage compared to large fruit consisting of big cells (Wismer et al., 1995).

Furthermore, 6-BA counteracts the inhibitory effect of GAs on reproductive bud induction. Exogenously applied 6-BA to spurs during the reproductive bud induction period lead to an increase in return bloom (Ramírez and Hoad, 1981), possibly due to an increase in ethylene that leads to reproductive bud induction and initiation (Bubán, 1996). Ramírez et al. (2004) found that most 'Red Delicious' apple seeds contained more cytokinins than GAs. They concluded that the commitment to reproductive bud induction depends on the ratio between the amount of endogenous cytokinins and GAs in apple seeds.

A PGR containing both $GA_{4+7}$ and 6-BA was developed to utilize their combined effect on fruit development. This combination affects both the fruit shape and size as the components stimulate cell division as well as expansion (Al-Wir, 1978; Petracek et al., 2003) and increase in seed number in some cultivars when applied at a concentration of 12.5 $\mu l \cdot L^{-1}$ at petal fall (Al-Wir, 1978).

*Abscisic acid and ethylene.* Abscisic acid (ABA), a natural plant hormone, play a role in several physiological processes (Addicott et al., 1964). An important function of this compound is protecting plants against abiotic stresses through regulating the initiation and maintenance of bud and seed dormancy and alleviating water stress by inducing stomatal closure (Rademacher, 2015; Taiz and Zeiger, 2002). Abscisic acid also leads to the abscission of apple flowers and young fruitlets (Edgerton, 1971). Greene et al. (2011) proposed that the abscission is due to reduction in carbohydrates for the developing structures as the stomatal closure limits gas exchange, i.e. photosynthesis (Beardsell and Cohen, 1975). Ethylene, a gaseous phytohormone, also regulate abscission of apple flowers and fruitlets (Taiz and Zeiger, 2002). ‘Golden Delicious’ fruitlets, for instance, experienced a stimulation in ethylene biosynthesis and an increase in sensitivity towards the hormone prior to drop (Dal Cin et al., 2005). Blanpied (1971) reported that ethylene levels in unpollinated ‘Golden Delicious’ flowers, which eventually abscised, were high after petal fall, while it decreased in pollinated flowers. Furthermore, ethylene negatively affects processes such as cell differentiation and expansion, while inducing seed germination (Taiz and Zeiger, 2002).

Both ethylene and ABA play an important role in fruit ripening (Jamnong and Gemma, 1991; Taiz et al., 2018). Apples are climacteric fruit and thus experience an increase in ethylene with ripening (McAtee et al., 2013). This spike in ethylene leads to the expression of genes involved with ripening processes like changes in color, flavor, texture as well as a rise in respiration and autocatalytic ethylene production (Oetiker and Yang, 1995). In peel color development of ‘Cripps’ Pink’ apples, Whale and Singh (2007) reported concurring results as they found a significant positive correlation between ethylene and anthocyanin with ripening. Abscisic acid also increases with maturity, which affects ethylene metabolism and stimulates processes such as color development in cherries and a reduction in firmness in apples (Falchi et al., 2014; Jamnong and Gemma, 1991; Setha et al., 2004).

## 4.2 Climate

### 4.2.1 Effect of temperature

The effect of temperature on apple development is important as it significantly contributes to the final fruit quality. Temperature is most influential at the early stages of apple fruit development. The period after full bloom, where maximum cell division takes place, is the most sensitive to temperature changes (Jackson et al., 1983; Warrington et al., 1999) as cell division is more responsive to temperature changes than cell expansion (Warrington et al., 1999). Warrington et al. (1999) investigated this phenomenon by exposing different cultivars to specific temperature regimes during the cell division and -expansion phase. The mean diameter expansion rate of the fruit was eight times more at a 25/15 ºC temperature regime than at 9/3 ºC during the cell division phase (10 to 40 d.a.f.b.). In contrast, the mean expansion rate of 'Delicious' apples only had a two-fold difference between the above-mentioned temperature regimes if applied during the cell expansion phase (40 to 80 d.a.f.b.). Greybe (1997) found concurring results as higher temperatures during the first 40 d.a.f.b. led to larger 'Royal Gala' apples. Warrington et al. (1999) also noted that although the cultivars had a similar response to different temperature regimes during the cell division phase, the magnitude of the individual expansion rates differed. While 'Braeburn' had the highest expansion rate at all the temperatures, 'Golden Delicious' had the lowest with 'Fuji' in between. Bergh (1990b) found that the season with higher temperatures during the 42 d.a.f.b. period led to larger fruit. He found that the increase in fruit growth rates of 'Starking' apples was due to an increase in cortical cell division rates.

Temperature also has a direct and indirect effect on the rate of reproductive bud differentiation by targeting the plastochron (Tromp, 1976). The direct effect refers to higher temperatures that leads to an increase in the meristem activity, thus reducing the plastochron. However, these high temperatures can also reduce reproductive bud formation as it increases vegetative growth which acts antagonistic towards reproductive growth (Jackson, 2003). The effect of temperature on the rate of reproductive bud differentiation seem to be cultivar dependent as it was higher at 13 ºC than 21 ºC in 'Jonagold' apples and lower at 13 ºC than 24 ºC in 'Cox Orange Pippin' apples (Verheij, 1996). Tromp (1976), however, found that reproductive bud differentiation of 'Cox Orange Pippin' was reduced when temperature changed from 17 to 24 ºC, seven weeks before harvest. Similar results were found for 'Summerred' apples where 13 to 20 ºC during six to seven weeks after full bloom progressed the reproductive bud formation, but 20 to 27 ºC had a retarding effect (Zhu et al., 1997). Considering both the direct and indirect effect together with the variability in responses towards temperature, it makes an important contribution in fruit development.

#### 4.2.2 Effect of light.

Tromp (1984) reported a significant increase in flower clusters in 'Cox's Orange Pippin' apples grown under a 14-hour rather than 8-hour photoperiod. In addition, low irradiation levels during the 49 d.a.f.b. period led to fewer reproductive buds due to lower carbohydrate availability (Tromp, 1984). The latter is supported by Jackson and Palmer (1977) who found that shading trees during the post-bloom period leads to lower flower bud formation in ‘Cox’s Orange Pippin’ apples. They also reported that shading reduced the fruit size and the dry matter content of the fruit.

## 5. Cracking of apple fruit.

### 5.1 General aspects.

Opara et al. (1997a) suggested that the first report on apple fruit cracking was made by Evans (1907) in 1907 and cracking still remains a problem. It is important to note that there is a difference between cracking and another physical disorder, splitting. Apple splitting entails a drastic form of cracking where a deep physical split occurs in the apple flesh causing the exposure of the cortical area of the fruit (Opara et al., 1997a). Cracking, on the other hand, was described by Milad and Shackel (1992) as "the physical failure of the fruit skin". Therefore, cracking entails fractures in the peel that do not expose the flesh to such an extent as splitting does, but rather affects the different layers of the peel. This disorder has caused major losses due to its effect on the appearance and internal quality of apples (Taylor and Knight, 1986; Verner, 1935). Apart from the less appealing nature of cracked apples, the open areas on the peel are also an entrance to decay organisms and give rise to moisture loss, shriveling and subsequently affects the marketability, storage and shelf life (Goode et al., 1975). A large range of apples including the cultivars Stayman (Byers et al., 1990), Cox's Orange Pippin (Goode et al., 1975), Gala (Opara et al., 2000), Fuji

(Kasai et al., 2008) and Cripps' Pink (Stern et al., 2013) are susceptible to different forms of cracking.

Shutak and Schrader (1948) concluded that cracks tend to develop and become more severe as 'York Imperial' apples ripen. Cracks also develop or increase after harvest after a period of cold storage (Goode et al., 1975; Khadivi-Khub, 2015). Furthermore, Shutak and Schrader (1948) found that biennial bearing affects the prevalence of cracks with fewer in "off" years even though larger fruit are more prone to cracking (De Salvador et al., 2006). De Salvador et al. (2006) found that vigorous trees produce fruit less susceptible to cracking.

The term "cracks" serve as a generalization for all the different types of cracks that are present on apple cultivars. These cracks can differ in terms of time of development, severity and position on the apple (Opara et al., 1997a). Skene (1965) placed the disorder into three groups; cracks that penetrate the cuticle, cracks in the outer cell layers of the peel and the extreme form where it stretches into the flesh of the apple. Regarding the position of the cracks, stem-end cracks have been reported on cultivars such as 'Fuji' (Kasai et al., 2008) and 'Gala' (Opara et al., 2000) while Stern et al. (2013) reported calyx-end cracking on 'Cripps' Pink' apples. Although there may be similarities in appearance in the different types of cracks, others do differ significantly from the rest. 'Golden Delicious' for instance, reacts to viruses, leading to the development of star-shaped cracks on either the cheek or the calyx-end of the fruit (Cropley, 1967). Therefore, it is important to distinguish between the types of cracks when seeking a solution to the specific problem.

### 5.2 Causes of cracking.

The complexity of the problem is illustrated by the fact that there are about 20 factors that can contribute to its development, either on their own or in combination (Opara et al., 1997a). Although several factors can play a role in the severity of the disorder, cracks can primarily be attributed to a fruit growth problem. Verner (1938) described one of the main causes of cracking as the excessive water absorption through the peel or roots at a late stage of fruit development, especially following a period of drought that reduced fruit growth. Verner (1935) stated that these drought conditions lead to an increase in the strength of apple tissues, usually first the xylem and phloem, and then a subsequent reduction in the dividing and enlarging ability of the cells. An excessive water supply thus leads to the swelling of the fruit with different growth rates among the tissues. Verner (1938) supported this idea by investigating the effect of cracking on different apple tissues. By comparing a susceptible cultivar, 'Stayman Winesap', with other less susceptible cultivars, a definite difference in the structure and growth of the hypodermal cells was noted. 'Stayman Winesap' apples displayed poor hypodermal cell growth towards the end of the growing season, whereas the cells kept up with the growth rate of the cortex of the apples in non-cracking cultivars (Verner, 1938). Furthermore, Verner (1938) described the hypodermal cells of 'Stayman Winesap' apples as "tangentially elongated", while in the other cultivars they were "isodiametric". Therefore, an abrupt increase of growth in the cortical region, causing the cortex to swell, leads to cracks in the peel due to limited elasticity of peel cells.

Such conditions are created by environmental or cultural factors that directly affect fruit growth or indirectly through altering the water relations within the fruit. Fruit water relations is influenced by precipitation, relative humidity (RH), irrigation and application of surfactants (Opara et al., 1997a). Goode et al. (1975) investigated the effect that early (before June drop), late (between June drop and harvest), combination of early and late and no irrigation had on the development of cracks in 'Cox's Orange Pippin'. At harvest, the trees that received no or early irrigation produced fruit with clear cracks, whereas the combination of early and late irrigated trees produced only a few fruits with cracks. This study was conducted in England, where the monthly rainfall during the active growing period in August was only 13 mm compared to the average of 60 mm, while evaporation was high. August was, however, followed by wet conditions with 126 mm rain in late September. Goode et al. (1975) concluded that the cracks were formed due to the contrasting conditions early during fruit development, and that consistent irrigation would reduce variability in water availability and thus reduce cracks. Opara et al. (2000) found that 'Gala' trees produced apples with more internal ring cracking when trees received continual irrigation instead of no irrigation and soil moisture levels were kept at field capacity up to harvest.

The presence of high RH reduces transpiration from the fruit and leaves. This decrease in water loss, together with an increase in rainfall or irrigation, creates perfect conditions for apples to swell to such an extent that cracks develop (Verner, 1938). Verner (1935) found that a prolonged RH close to saturation or saturated (99-100%) led to crack development, whereas RH less than 90% resulted in none. Low RH can also contribute to cracking by worsening drought conditions through increasing the driving force for transpiration losses (Kader, 1986; Louw, 1948). Byers et al. (1990) found that when immersing 'Stayman' apples in anionic (GR-5) as well as nonionic (X-77) surfactants, water absorption was enhanced and led to increased cracking. The improved absorption of water was primarily through injured areas on the cuticle and the fruit lenticels.

Cultural practices that affect fruit growth through cell enlargement can contribute to the development of cracking (Gourley and Howlett, 1941). Trees with low vigor and a light crop produce fruit that are more susceptible to cracking (Louw, 1948; Shutak and Schrader, 1948). Therefore, practices such as thinning can potentially increase cracking (Bergh, 1990a). Furthermore, Opara et al. (2000) investigated the possible role of mineral nutrition, such as calcium (Ca) and nitrogen (N), on apple cracking. Calcium plays a vital role in cellular structure, specifically by increasing the strength of cell walls and membranes (White and Broadley, 2003). Therefore, a deficiency in Ca can contribute to cracking in apples (Opara et al., 1997b). In a later study, Opara et al. (2000) found that Ca could also have the opposite effect as its concentration was significantly higher in cracked 'Gala' fruit than non-cracked. They suggested that high concentrations of Ca may decrease the elasticity of the cell walls, which subsequently increases the chance of the cells to rupture when exposed to abrupt changes in growth conditions. Opara et al. (2000) found no significant differences in N concentration between cracked and normal ‘Gala’ apples. This supports results by Stiles et al. (1959) who reported that exogenously applied urea had no effect on ‘Stayman’ fruit cracking. However, a slight positive correlation between N application and crack development in 'Cox's Orange Pippin' apples was reported by Goode et al. (1975). Therefore, Opara et al. (2000) concluded that more research is necessary to understand the effect of N on apple cracking.

Certain anatomical characteristics of the apple peel play an important role in crack formation. Several studies have indicated that the outer layers of the peripheral tissue of apples, including the epidermal cells and the cuticle, can influence the susceptibility of apples to cracking. Ginzberg and Stern (2016) and Shutak and Schrader (1948) described the preferred anatomy of a peel that is less susceptible to crack development. Apple peels with dense epidermal cells tightly fixed to each other are less likely to develop cracks under adverse conditions. According to Tetley (1930), the cutin structure is correlated with crack development in some fruit. This was supported by Shutak and Schrader (1948) who observed a positive correlation between cuticle thickness and cracked fruit in 'York Imperial' apples. They concluded that apples with thin, smooth and continuous cutin are less likely to develop cracks under conditions that lead to an extreme volume increase compared to apples with thick cutin. Interestingly, Tetley (1930) and Shutak and Schrader (1948) discovered that cultivars with irregular cutin that penetrates between the epidermal cells are more prone to cracking than those with cutin that borders on the apical part of epidermal cell walls.

These characteristics of peels are subject to change under certain environmental conditions. Both light and temperature fluctuations affect the structure of the apple peel (Verner, 1938). Shutak and Schrader (1948) reported the presence of cracks on the shaded side rather than non-shaded side of apples, while in 'Stayman Winesap' (Verner, 1938), 'Gala' (Opara et al., 1997b) and 'James Grieve' (Tetley, 1930) fruit also cracked on the light exposed side. Irrespective of the sun or shade conditions, it is important to note that the affected area possessed a thicker and less flexible cuticle (Opara et al., 1997a). According to Verner (1935), cracking of 'Stayman Winesap' apples was not influenced by air temperature, but Tetley (1930) found a negative correlation between temperature and cracking. In cultivars, such as 'James Grieve' and 'Beauty of Bath', Tetley (1935) found that exposure to lower temperatures early during fruit development led to thick cuticles with lower elasticity, i.e. a peel structure that is prone to cracking. Some apples suffer from irregularities such as russeting and sunburn that decreases fruit quality. These irregularities do not cause cracking per se, but can contribute to it (Verner, 1935).

### 5.3 Control of cracking.

Several methods have been tried to reduce apple fruit cracking. The wide range of cultivars with varying susceptibility to cracking complicates the mitigation process. The causal factors also vary, therefore different methods should be considered.

#### 5.3.1 Cultural practices.

Shutak and Schrader (1984) suggested cultural practices that stimulate apple tree vigor can be implemented to reduce cracking. Byers et al. (1990) found that neither summer nor winter pruning had a significant effect on fruit cracking in ‘Stayman’/seedling trees, while scoring reduced apple fruit cracking when two scores were made with a carpet knife during summer. Improving the nutritional status of trees through Ca fertilization proved an effective method to reduce cracks in some instances (Powers and Bollen, 1947). Furthermore, optimal management of the water supply can also decrease cracking (Goode et al., 1975). Irrigation scheduling is thus of great importance as water relations in apple trees and fruit can be altered. In modern orchards these factors should all be maintained optimally, but it could sometimes be difficult to maintain correct moisture levels when environmental conditions are extreme e.g. during drought or high rainfall periods.

### 5.3.2 Chemical control.

Chemical control of cracking entails the use of PGRs. These substances alter the growth of peel components such as the cuticle, epidermal and hypodermal layers. The use of PGRs are specific in terms of concentration and time of application and can differ in effectiveness among different cultivars. GA is one of the phytohormones that successfully reduces apple cracking (Taylor and Knight, 1986). Byers et al. (1990) reduced cracking from 58% to 21% in 'Stayman' apples with four $GA_{4+7}$ applications at 20 mg·L$^{-1}$ during late summer on 24 July, 3, 11 and 17 August, but spring applications were unsuccessful. The spring applications also reduced return bloom the following year. Knoche et al. (2011) also found four $GA_{4+7}$ applications at 10 mg·L$^{-1}$ to be successful in controlling micro-cracking on 'Golden Delicious' apples if applied early during the cell division phase (6, 16, 26 and 38 d.a.f.b.). $GA_{4+7}$ promoted enlargement of hypodermal and epidermal cells (Taylor and Knight, 1986). Knoche et al. (2011) thus concluded that this effect on cell enlargement would enable the cells to stay connected in fast growing circumstances. $GA_3$ is generally used to "delay fruit peel senescence" but is ineffective in controlling cracking in apples (Stern et al., 2013).

$GA_{4+7}$ is also used in combination with 6-BA, due to their involvement in the cell cycle and elongation process. Stern et al. (2013) investigated the use of this combination to control calyx-end cracking in 'Cripps' Pink' apples. As maximum fruit growth occurs between 60 and 100 d.a.f.b., they found that three applications at 40 mg·L$^{-1}$ with two-week intervals from 60 d.a.f.b. led to the lowest crack percentage. Ginzberg et al. (2014) later stated that lower concentrations of the combination (5 mg·L$^{-1}$ 6-BA and 5 mg·L$^{-1}$ $GA_{4+7}$) is most effective on apples when applied during the cell division phase. These hormones seem to target the epidermis (Ginzberg et al., 2014; Ginzberg and Stern, 2016; Stern et al., 2013). While the cytokinin component stimulates the cell division process, the $GA_{4+7}$ leads to larger cells. Stern et al. (2013) concluded that these two processes lead to an increased epidermal cell density and therefore improves the elasticity of the peel. Apples are thus more capable of withstanding internal stress caused by extreme growth conditions. Despite the effectiveness of this combination on 'Cripps' Pink', not all cultivars respond as well. Concentrations of 0, 20 and 40 µl·L$^{-1}$ failed to reduce cracks on 'Niepling Stayman' apples when applied at balloon stage followed by four weekly applications from petal fall (Visai et al., 1989). Costa et al. (1983) also found no reduction in cracking on 'Stayman Red' apples when 25 $\mu l \cdot L^{-1}$ was applied at 35, 61, 76 and 109 d.a.f.b.

The PGRs daminozide and paclobutrazol (PBZ) were also evaluated as possible controlling agents of apple cracking. Visai et al. (1989) found that the crack percentage on 'Niepling Stayman' apples progressively increased from no treatment to three and five applications of PBZ at 250 $mg \cdot L^{-1}$ applied at the same times as the 6-BA+$GA_{4+7}$ above. Promising results were however reported after foliar applications of daminozide (Byers et al., 1990; Costa et al., 1983; Sullivan and Widmayer, 1970). Concentrations of 1000 and 2000 $\mu l \cdot L^{-1}$, applied at 42, 49, 76 and 109 d.a.f.b., led to a significant reduction in percentage cracking of 'Stayman Red' apples (Costa et al., 1983). While Costa et al. (1983) found that 2000 $\mu l \cdot L^{-1}$ caused a reduction in fruit size in both the treated fruit and in the following season, Sullivan and Widmayer (1970) reported an increase in the fruit weight. Daminozide is, however, no longer allowed as PGR and therefore not a solution for the apple cracking disorder (Hathaway, 1993).

## Conclusion

The development of an apple is a complex sequence of events starting with flower induction and culminating in fruit harvest. Fruit development is sensitive to several cultural and climatic factors and should be considered when producing apples of optimal quality. Cracking is an example of a detrimental consequence following cultural and climatic conditions that leads to extreme growth conditions. Although pruning strategies and moisture management serve as possible controlling mechanisms, the use of PGRs have become the focus of several studies. Positive results have been found with GAs and 6-BA when applied early in the fruit development as the cell size and number and subsequently the cell elasticity is manipulated. Apple cultivars, however, differ in the type of cracks they develop as well as their response towards chemical control.

## Literature cited

Abdulkadyrov, S.K., Sh.G. Batyrkhanov, and B.R. Dzhabaev. 1972. Trudy Dagestanskogo (in Russian). Sel'skokhozyaistvennogo Instituta 22:58-71 (Hort. Abstr.43: 4999).

Addicott, F.T., H.R. Carns, J.L. Lyon, O.E. Smith, and J.L. McMeans. 1964. The physiology of abscission, p. 687–703. In: Nitsch, J.P. Regulaateurs de la croissance vegetale. CNRS, Paris, Fra.

Al-Wir, A.I. 1978. The influence of growth regulators on the anatomical, morphological development and quality of apple fruits. Iowa State Univ., Ames, Iowa, USA, PhD Diss.

Bain, I.M. and R.N. Robertson. 1951. The physiology of growth in apple fruit. Aust. J. Sci. Res. 4:75-91.

Beardsell, M.F. and C. Cohen. 1975. Relationships between leaf water status, abscisic acid levels and stomatal resistance in maize and sorghum. Plant Physiol. 56(2):207-212.

Bell, H.P. 1937. The protective layers of the apple. Canad. J. Res. C 15:391-402.

Bergh, O. 1985a. Morphogenesis of *Malus domestica* cv. Starking flower buds. S. Afr. J. Plant Soil 2(4):187-190.

Bergh, O. 1985b. Effect of the previous crop on cortical cell number of *Malus domestica* cv. Starking Delicious apple flower primordia, flowers and fruit. S. Afr. J. Plant Soil 2:191-196.

Bergh, O. 1990a. Effect of time of hand-thinning on apple fruit size. S. Afr. J. Plant Soil 7(1):1-10.

Bergh. O. 1990b. Effect of temperature during the first 42 days following full bloom on apple fruit growth and size at harvest. S. Afr. J. Plant Soil 7(1):11-18.

Blanpied, G.D. 1971. A study of ethylene in apple, red raspberry, and cherry. Plant Physiol. 49:627-630.

Bollard, E.G. 1970. The physiology of developing fruits, p. 387-425. In A.C. Hulme (ed.) The biochemistry of fruits and their products. Academic Press, London.

Bound, S. 2001. The influence of endothal and 6-benzyladenine on crop load and fruit quality of red ‘Delicious’ apple. J. Hort. Sci. Biotechnol. 76(6):691-699.

Bound, S.A. and C.R. Summers. 2001. The effect of pruning level and timing on fruit quality in red 'Fuji' apple. Acta Hort. 557:295-298 (abstr.).

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

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

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

Bukovac, M.J. and S. Nakagawa. 1967. Comparative potency of gibberellins in inducing parthenocarpic fruit growth in *Malus sylvestris* Mill. Experientia 23:865.

Byers, R.E., D.H. Carbaugh, and C.N. Presley.1990. 'Stayman' fruit cracking as affected by surfactants, plant growth regulators and other chemicals. J. Amer. Soc. Hort. Sci. 115(3):405-411.

Cain, J.C. 1971. Effects of mechanical pruning of apple hedgerows with a slotting saw on light penetration and fruiting. J. Amer. Soc. Hort. Sci. 96(5):664-667.

Costa, G., C. Giulivo, and A. Ramina. 1983. Influence of growth regulators on apple fruit cracking (cv. "Stayman Red"). Acta Hort. 137:366-369 (abstr.).

Cresti, M., F. Ciampolini, and S. Sansavini.1980. Ultrastructural and histochemical features of pistil of *Malus communis:* the stylar transmitting tissue. Scientia Hort. 12:327-337.

Cropley, R. 1967. Varietal reactions to viruses causing star crack and russet rings on apple fruit. J. Hort. Sci. Biotechnol. 43(2):157-165 (abstr.).

Da Silva, J.A.T. 2012. Is BA (6-Benzyladenine) BAP (6-Benzylaminopurine)? Asian Australas. J. Plant. Sci. Biotechnol 6(1):121-124.

Dal Cin, V., A. Boschetti, A. Dorigoni, and A. Ramina. 2007. Benzylaminopurine application on two different apple cultivars (*Malus domestica*) displays new and unexpected fruitlet abscission features. Ann. Bot. 99:1195-1202.

Dal Cin, V., M. Danesin, A. Boschetti, A. Dorigoni, and A. Ramina. 2005. Ethylene biosynthesis and perception in apple fruitlet abscission (*Malus domestica* L. Borck). *J*. Exp. Bot. 56(421):2995-3005.

Davis, D.E. 2002. Inhibition of flower bud initiation and development in apple by defoliation, gibberellic acid and crop load manipulation. Virginia Polytechnic Inst. State Univ., Blacksburg, Virginia, PhD. Diss.

De Salvador, F.R., M. Fisichella and M. Fontanari. 2006. Correlations between fruit size and fruit quality in apple trees with high and standard crop load levels. J. Fruit Ornam. Plant Res. 14:113-122.

Dennis, F.G. 1967. Apple fruit-set: evidence for a specific role of seeds. Science 156:71-73.

Devoghalaere, F., T. Doucen, B. Guitton, J. Keeling, W. Payne, T.J. Ling, J.J. Ross, I.C. Hallet, K. Gunaseelan, G.A. Dayatilake, R. Diak, K.C. Breen, D.S. Tustin, E. Costes, D. Chagné, R.J. Schaffer, and K.M. David. 2012. A genomics approach to understanding the role of auxin in apple (*Malus* x *domestica*) fruit size control. BMC Plant Biol. 12:7.

Drazeta, L., Lang, A., Hall, A.J., Volz, R.K., and Jameson, P.E. 2004. Modelling the influence of seed set on fruit shape in apple. J. Hort. Sci. Biotechnol. 79(2):241-245.

Drazeta, L.R. 2002. Structure, function and quality development in apples. Massey Univ., Palmerston North, New Zealand, PhD Diss.

Edgerton, L.J. 1971. Apple abscission. HortSci. 6:378–382.

Elsysy, M.A. and P.M. Hirst. 2017. The role of spur leaves, bourse leaves, and fruit on local flower formation in apple: an approach to understanding biennial bearing. HortSci. 52(9):1229-1232.

Esau, K. 1977. Anatomy of Seed Plants. 2nd ed. Wiley, New York.

Evans, I.B.P. 1907. Notes on plant diseases. I: An apple disease (*Coniothecum chomatosporum,* Corda). Transvaal Agric. J. 5(19):680-681.

Falchi, R., L. Zanon, G. Vizzotto, and M. Noferini. 2014. Use of abscisic acid on climacteric (apple) and non-climacteric (cherry) fruits. Acta Hort. 1042:223-229.

Faust, M. 1989. Physiology of temperate zone fruit trees. Wiley, New York.

Ferree, D.C., S.C. Myers, C.R. Rom, and B.H. Taylor. 1984. Physiological aspects of summer pruning. Acta Hort. 146:243-252 (abstr.).

Foster, T., R. Johnston, and A. Seleznyova. 2003. A morphological and quantitative characterization of early floral development in apple (*Malus domestica* Borkh.). Ann. Bot. 92:199-206.

Gardner, V.R., F.C. Bradford, and H.D. Hooker. 1952. The fundamentals of fruit production. Pruning – The season. 3rd ed. McGraw-Hill, New York, Toronto, London.

Ginzberg, G. and R.A. Stern. 2016. Strengthening fruit-skin resistance to growth strain by application of plant growth regulators. Sci. Hort. 198:150-153.

Ginzberg, I., E. Fogelman, L. Rosenthal, and R.A. Stern. 2014. Maintenance of high epidermal cell density and reduced calyx-end cracking in developing 'Pink Lady' apples treated with a combination of cytokinin 6-benzyladenine and gibberellins A4+A7. Sci. Hort. 165:324-330.

Goode, J.E., M.M. Fuller, and K.J. Hyrycz. 1975. Skin-cracking of Cox's Orange Pippin apples in relation to water stress. J. Hort. Sci. 50:265-269.

Gourley, J.H. and F.S. Howlett. 1941. Modern fruit production. Macmillan, New York.

Greene, D.W., J.R. Schupp, and H.E. Winzeler. 2011. Effect of abscisic acid and benzyladenine on fruit set and fruit quality of apples. HortSci. 46(4):604-609.

Greene, D.W.J. 1993. Effects of $GA_4$ and $GA_7$ on flower bud formation and russet development on apple. J. Hort. Sci. 68(2):171-176 (abstr.).

Greybe, E. 1997. The pre- and post-anthesis factors influencing the fruit size of 'Royal Gala' apples in South Africa. Univ. of Pretoria, Pretoria, MSc Agric. Thesis.

Habdas, H., L.S. Jankiewicz, and B. Borkowska. 1982. Changes in the anatomical structure of apple fruitlet pedicels preceding June drop. Acta Agrobot. 35:11-23.

Harker, F.R., R.J. Redgwell, I.C. Hallett, S.H. Murray and G. Carter. 1997. Texture of fresh fruit. Hort. Rev. 20:121-124.

Hathaway, J.S. 1993. The EPA's mismanagement of an agricultural chemical, p. 337-343. In: Pimentel, D., H. Lehman. The pesticide question. Springer, Boston, MA.

Hättasch, C., H. Flachowsky, D. Kapturska, and M. Hanke. 2008. Isolation of flowering genes and seasonal changes in their transcript levels related to flower induction and initiation in apple (*Malus domestica*). *Tree Physiol.* 28(10):1459–1466.

Hoover, E., N. De Silva, S. Mcartney, and P. Hirst. 2004. Bud development and floral morphogenesis in four apple cultivars. J. Hort. Sci. Biotechnol. 79(6):981-984.

Hopkins, W.G. and N.P.A. Hüner. 2009. Introduction to plant physiology. 4th ed. Wiley, New York.

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

Jackson, J.E. 2003. Biology of apples and pears. Cambridge University press, Cambridge, U.K.

Jackson, J.E. and J.W. Palmer. 1977. Effects of shade on the growth and cropping of apple trees. II. Effects on components of yield. J. of Hort. Sci. 52(2):253-266.

Jackson, J.E., P.J.C Hamer, and M.F. Wickenden. 1983. Effects of early spring temperatures on the set of fruits of Cox's Orange Pippin apple and year-to-year variation in its yields. Acta Hort. 139:75–82 (abstr.).

Jamnong, U. and H. Gemma. 1991. Changes in abscisic acid content of peel and pulp of 'Jonagold' apples during pre- and post-harvest periods. J. Jpn. Soc. Hort. Sci. 60(2):443-448.

Janick, J., J.N. Cummins, S.K. Brown, and M. Hemmat. 1996. Apples, p. 1-77. In: J. Janick and J.N. Moore (eds.). Fruit Breeding, Vol. I, Tree and Tropical fruits. Wiley, New York.

Kader, A.A. 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. Food technol. 40(5):99-104.

Karssen, C.M., S. Zagorski, J. Kepczynski, and S.P.C. Groot. 1989. Key role for endogenous gibberellins in the control of seed germination. Ann. of Bot. 63(1):71-80.

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

Khadivi-Khub, A. 2015. Physiological and genetic factors influencing fruit cracking. Acta Physiol Plant 37:1718.

Kilili, A.W., M.H. Behboudian, and T.M. Mills. 1996. Composition and quality of 'Braeburn' apples under reduced irrigation. Sci. Hort. 67(2):1–11.

Knoche, M., B.P. Khanal, and M. Stopar. 2011. Russeting and microcracking of 'Golden Delicious' apple fruit concomitantly decline due to Gibberellin $A_{4+7}$ application. J. Amer. Soc. Hort. Sci. 136(3):159-164.

Koltunow, A. 1993. Apomixis: Embryo sacs and embryos formed without meiosis or fertilization in ovules. Plant Cell 5(10):1425-1437.

Koutinas, N., G. Pepelyankov, and V. Lichev. 2010 Flower induction and flower bud development in apple and sweet cherry. Biotechnol. Equip. 24(1):1549-1558.

Kozma, P., J. Nyeki, M. Soltesz, and Z. Szabo. 2003. Floral biology, pollination and fertilization in temperate zone fruit species and grape. Akadémiai Kiadó, Budapest.

Kraus, E.J. and G.S. Ralston. 1916. The pollination of pomaceous fruits III. Gross vascular anatomy of the apple. Techn. Bull. Oregon Agric. Exp. Sta. 138:4-12.

Li, K. 2001. Physiological effects of summer pruning in apple trees. Cornell Univ., Ithaca, New York, USA, PhD Diss.

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

Louw, A.J. 1948. Investigations on the cracking of Ohenimuri apples. Farming S. Africa. 23:596-602.

Luckwill, L.C., P. Weaver, and J. Macmillan. 1969. Gibberellins and other growth hormones in apple seeds. J. of Hort. Sci. 44(4):413-424.

Malladi, A. and L. K. Johnson. 2011. Expression profiling of cell cycle genes reveals key facilitators of cell production during carpel development, fruit set, and fruit growth in apple (*Malus domestica* Borkh.). J. Expt. Bot*. 62(1)*:205-219.

McArtney, S. 2011. Apple growth and crop load management. Fruit Notes 76:6-9.

McAtee, P., S. Karim, R. Schaffer, and K. David. 2013. A dynamic interplay between phytohormones is required for fruit development, maturation and ripening. Front. Plant Sci. 4:79.

Milad, R.E. and K.A. Shackel. 1992. Water relation of fruit end cracking in French prune (*Prunus domestica* L. cv. French). J. Am. Soc. Hort. Sci. 117:824–828.

Miller, R.H. 1982. Apple fruit cuticles and the occurrence of pores and transcuticular canals. Ann. Bot. 50:355-71.

Murneek, A. E. 1954. The embryo and the endosperm in relation to fruit development, with special reference to the apple. Proc. Am. Soc. Hort. 64:573-582.

Myers, S.C. and D.C. Ferree. 1984. Summer pruning for size control in a high density ‘Delicious’/M9 system. Acta Hort. 146:253-261.

Naor, A., I. Klein, and I. Doron. 1995. Stem water potential and apple fruit size. J. Am. Soc. Hort. Sci. 120:577–582.

Naor, A., I. Klein, I. Doron, Y. Gal, Z. Ben-David, and B. Bravdo. 1997. The effect of irrigation and crop load on stem water potential and apple fruit size. J. Hort. Sci. 72(5):765-771.

Nitsch, J. 1970. Hormonal factors in growth and development, p. 427-472. In: A.C. Hulme (eds.). The Biochemistry of Fruits and Their Products, Vol. II. Academic Press, London.

Oetiker, J.H. and S.F. Yang. 1995. The role of ethylene in fruit ripening. Acta Hort. 398: 167-178.

Opara, L.U., A.J. Hodson, and C.J. Studman. 2000. Stem-end splitting and internal ring-cracking of 'Gala' apples as influenced by orchard management practices. J. Hort. Sci. Biotechnol. 75(4):465-469.

Opara, L.U., C. J. Studman, and N. H. Banks. 1997b. Sunlight affects the incidence of internal ring cracking and other physical attributes of ‘Gala’ apples. J. Tree Fruit Production 2(1):45-52.

Opara, L.U., J. Studman, and N.H. Banks. 1997a. Fruit splitting and cracking. Hort. Rev. 19:217-262.

Pacini, E. and G.G. Franchi. G.G. 1988. Amylogenesis and Amylolysis during pollen grain development. p. 181-186. In: M. Cresti, P. Gori and E. Pacini (eds.). Sexual reproduction in higher plants. Springer, Berlin, Heidelberg.

Palmer-Jones, T, and P.G. Clinch. 1966. Observations on the pollination of apple trees (*Malus sylvestris* Mill.). New Zeal. J. Agr. Res. 9(2):191-196.

Petracek, P.D., F.P. Silverman and D.W. Greene. 2003. A history of commercial plant growth regulators in apple production. HortSci. 38(5):937-942.

Powers, W.L. and W.B. Bollen. 1947. Control of cracking of fruit by rain. Science 105:334-335.

Pratt, C. 1988. Apple flower and fruit: morphology and anatomy. Hort. Rev. 10:273-280.

Prive, J.P., D.C. Elfving, and J.T.A. Proctor. 1988. Pedicel characteristics of four apple cultivars. Fruit Var. J. 45(4):122-125.

Rademacher, W. 2015. Plant growth regulators backgrounds and uses in plant production. J Plant Growth Regulat. 34:845-872.

Ramírez, H. 1998. Identification of endogenous gibberellins in 'Red Delicious' apple seeds. Acta Hort. 463:231-234.

Ramírez, H. 2001. Physiology of blooming of a low chilling requirement 'Golden Delicious' apple mutant. Acta Hort. 565:87-90.

Ramírez, H. and Hoad, G.V. 1981. Effects of growth substances on fruit-bud initiation in apple. Acta Hort. 120:131-136.

Ramírez, H., G.V. Hoad, A. Benavides, and E. Rangel. 2001. Gibberellins in apple seeds and the transport of [$^3$H]-$GA_4$. Revista de la Sociedad Química de México 45(2):47-50.

Ramírez, H., J. Torres, A. Benavides, J. Hernández, and V. Robledo. 2004. Fruit bud initiation in apple cv. Red Delicious linked to gibberellins and cytokinins. Rev. Soc. Quím. Méx. 48:7-10.

Rom, C.R. 1992. Spur pruning 'Delicious' apples for improved spur quality and yield. Acta. Hort. 322:55-67 (abstr.).

Saure, M.C. 1987. Summer pruning effects in apple – a review. Scientia Hort. 30:253-282.

Sedgley, M. 1990. Flowering of deciduous perennial fruit crops. Hort. Rev. 12:223–264.

Setha, S., S. Kondo, N. Hirai, and H. Ohigashi. 2004. Xanthoxin, abscisic acid and its metabolite levels associated with apple fruit development. Plant Sci. 166(2):493-499.

Shoemaker, J.S. 1926. Pollen Development in the apple, with special reference to chromosome behavior. Bot. Gaz. 81(2):148–172.

Shutak, V. and A.L. Schrader. 1948. Factors associated with skin-cracking of York Imperial apples. Proc. Am. Soc. Hort. Sci. 51:245-257.

Skene, D.S. 1965. Cracking and russeting in apple fruits, p. 99-101. In: Annu. Rep. East Mall. Res. Sta. for 1964.

Smith, R.C., P.R. Matthews, P.H.D. Schunmann, and P.M. Chandler. 1996. The regulation of leaf elongation and xyloglucan endotransglycosylase by gibberellin in 'Himalaya' barley (*Hordeum vulgare* L.). J. Expt. Bot. 47(302):1395-1404.

Stern, R., R. Ben-Arie, and I. Ginzberg. 2013. Reducing the incidence of calyx cracking in ‘Pink Lady’ apple using a combination of cytokinin (6-benzyladenine) and gibberellins ($GA_{4+7}$). J. Hort. Sci. Biotechnol. 88(2):147–153.

Stiles, W.C., N.F. Childers, M.J. Prusik, and T.N. Kom. 1959. Effects of urea sprays and pesticides on russeting and cracking of Stayman apple. Proc. Am. Soc. Hort. Sci. 74:25-29 (abstr.).

Stopar, M., M. Resnik, and V.Z. Pongrac. 2001. Non-structural carbohydrate status and $CO_2$ exchange rate of apple fruitlets at the time of abscission influenced by shade, NAA or BA. Scientia Hort. 87:65-76.

Sullivan, D.T. and F.B. Widmayer. 1970. The effect of alar on fruit cracking of ‘Stayman winesap’ apple. Fruit Var. Hort. Dig. 24:17-18 (abstr.).

Taiz, L. and E. Zeiger. 2002. Plant physiology. 3rd ed. Sinauer Associates, Sunderland, MA.

Taiz, L., E. Zeiger, I.M. Moller, and A. Murphy. 2018. Plant physiology and development. 6th ed. Oxford Univ. Press, New York, NY.

Taylor, B. H. 1982. The influence of summer pruning and fruit cropping on growth, carbohydrate and nutrient element status of apple trees. The Ohio State University, Ohio, USA, PhD Diss.

Taylor, B.H. and D.C. Ferree. 1984. The influence of summer pruning and cropping on growth and fruiting of apple. J. Amer. Soc. Hort. Sci. 109(1):17-24.

Taylor, D.R. and J.N. Knight. 1986. Russeting and cracking of apple fruit and their control with plant growth regulators. Acta Hort. 179:819-820 (abstr.).

Tetley, U. 1930. A study of the anatomical development of the apple and some observations on the pectic constituents of the cell walls. J. Pomol. Hort. Sci. 8:153-171.

Trewavas A.J. and R.E. Cleland. 1983. Is plant development regulated by changes in the concentration of growth substances or by changes in the sensitivity to growth substances? Trends Biochem. Sci. 8(10):354-357.

Tromp, J. 1976. Flower-bud formation and shoot growth in apple as affected by temperature. Sci. Hort. 5 (4):331-338.

Tromp, J. 1984. Flower-bud formation in apple as affected by air and root temperature, air humidity, light intensity, and day length. Acta Hort. 149:39-48 (abstr.).

Tromp, J., H. Jonkers, and S. J. Wertheim. 1976. Grondslagen van de Fruitteelt. Staatsuitgeverÿ,’s-Gravenhage, The Netherlands.

Tukey, H. B. and J.0. Young. 1942. Gross morphology and histology of developing fruit of the apple. Bot. Gaz. 104(1):3-25.

Verheij, F.A. 1996. Morphological and physiological aspects of the early phases of flower bud formation of apple. Wageningen Agricultural Univ., Wageningen, The Netherlands, PhD. Diss.

Verner, L. 1935. A physiological study of cracking in Stayman Winesap apples. J. Agr. Res. 51:191-222.

Verner, L. 1938. Histology of apple fruit in relation to cracking. J. Agr. Res. 5:813-824.

Visai, C., O. Failla, and T. Eccher. 1989. Effects of promalin and paclobutrazol on cracking and quality of ‘Niepling Stayman' apples. Acta Hort. 239:451-453 (abstr.).

Warrington, I.J., T.A. Fulton, E.A. Halligan, and H.N. de Silva. 1999. Apple fruit growth and maturity are affected by early season temperatures. J. Amer. Soc. Hort. Sci. 124(5):468–477.

Way, R.D. 1995 Pollination and fruit set of fruit crops. N. Y. State Agr. Expt. Sta. 237.

Whale, S.K. and Z. Singh. 2007. Endogenous ethylene and color development in the skin of ‘Pink Lady’ apple. J. Amer. Soc. Hort. Sci. 132(1):20-28.

White, P.J. and M.R. Broadley. 2003. Calcium in plants. Ann. Bot. 92: 487-511.

Wismer, P.T., J.T.A. Proctor, and D.C. Elfving. 1995. Benzyladenine affects cell division and cell size during apple fruit thinning. J. Amer. Soc. Hort. Sci. 120(5):802-807.

Wünsche, J.N., J.W. Palmer, and D.H. Greer. 2000. Effects of crop load on fruiting and gas-exchange characteristics of 'Braeburn'/M.26 apple trees at full canopy. J. Amer. Soc. Hort. Sci. 125(1):93–99.

Ystaas, J. 1992. Effects of summer pruning on yield, fruit size, and fruit quality of the apple cultivar 'Summerred'. Acta Hortic. 322:277-282.

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

Zeevaart, J.A. 1971. Effects of photoperiod on growth rate and endogenous gibberellins in the long-day rosette plant spinach. Plant Phys. 47(6):821-827.

Zhu, L.H., O. Borsboom, and J. Tromp. 1997. The effect of temperature on flower-bud formation in apple including some morphological aspects. Sci. Hort. 70(1):1-8 (abstr.).

Zielinski, Q.B. 1955. Modern systematic pomology. WM. C. Brown Company, Dubuque, Iowa.

# PAPER 1: Increasing the Pedicel Length of ‘Nicoter’, ‘Fuji’ and ‘Cripps’ Pink’ Apples Using 6-Benzyladenine and Gibberellins ($GA_{4+7}$).

*Additional index words.* Fruit set, yield, fruit quality, fruit size, pedicel size, return bloom.

---

***Abstract.***

**The apple pedicel is an important structure that plays a crucial role in fruit quality. The pedicel dimensions of certain cultivars in the Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) region of South Africa has become problematic as it is short, stubby and rigid and causes losses pre- and post-harvest. The purpose of this study was to evaluate the efficacy of $GA_{4+7}$ and the combination of $GA_{4+7}$ and 6-BA on apple pedicel elongation of cultivars Fuji, Nicoter and Cripps’ Pink. In addition, the effect on fruit set, yield, fruit quality and return bloom was also evaluated to determine whether side-effects occurred. In the first season, both $GA_{4+7}$ and $GA_{4+7}$ + 6-BA were applied three times between pink bud stage and full bloom at 5, 10 and 20 $mg{\cdot}L^{-1}$. Both products had mild effects on the pedicel length. The highest rate of $GA_{4+7}$ + 6-BA thinned ‘Nicoter’ and ‘Cripps’ Pink’ fruitlets and reduced the yield and yield efficiency of the ‘Cripps’ Pink’ apples. Therefore, the combination was omitted in 2018/2019. In the second season, $GA_{4+7}$ was applied at higher rates (50, 100 and 200 $mg{\cdot}L^{-1}$) once or twice between tight cluster stage and full bloom. Additional low rates, 20 and 10 $mg{\cdot}L^{-1}$, were also applied two and four times, respectively, between tight cluster and full bloom. Multiple $GA_{4+7}$ applications resulted on average in longer pedicels than the single $GA_{4+7}$ application. Although the higher $GA_{4+7}$ rates increased pedicel length, double $GA_{4+7}$ application at 200 $mg{\cdot}L^{-1}$ reduced fruit set and yield on ‘Nicoter’ and ‘Cripps’ Pink’ and decreased the return bloom of ‘Cripps’ Pink’ apples. On ‘Nicoter’ and ‘Fuji’, calyx-end ribbing was also generally increased by the $GA_{4+7}$ treatments, but was very slight and not of any horticultural concern. The recommended treatments to increase pedicel length are 50 $mg{\cdot}L^{-1}$ $GA_{4+7}$, applied twice, 10 $mg{\cdot}L^{-1}$ $GA_{4+7}$, applied four times, and 20 $mg{\cdot}L^{-1}$ $GA_{4+7}$, applied twice for ‘Nicoter’, ‘Fuji’ and ‘Cripps’ Pink’, respectively.**

---

The apple pedicel or stalk is an important component contributing to the final flower quality and therefore the quality of the subsequent fruit (Habdas et al., 1982; Prive et al., 1988). This structure connects the vegetative and reproductive parts of a tree by attaching the fruit and serving as a conduit for water, mineral, hormone and assimilate transport. While most of the research on apple pedicels has been devoted to the vascular anatomy and the abscission of fruit, relatively little research has been done on the structural development (Habdas et al., 1982; Kraus and Ralston, 1916). Prive et al. (1988) did, however, investigate the pedicel growth patterns of four apple cultivars, McIntosh, Spartan, Idared and Delicious, and found that elongation is completed at full bloom and the diameter expansion concludes three to four weeks after full bloom.

The pedicel length and diameter are important as it determines the ability of the fruit to withstand the impact of neighboring apples pushing against each other, the environment and farming practices. However, in the Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) area of South Africa, the pedicels of certain cultivars, e.g. Cripps' Pink, Nicoter and Fuji, are short, stubby and rigid. Such pedicels increase the density within apple clusters (Botanically cyme) which leads to bruising and drop of apples within the same inflorescence during harvest. Furthermore, the rigid pedicels tear out at the stem end of the fruit during picking or puncture apples that are being transported in picking bags and bins (S. Reynolds and J. Moelich, personal communication). This has become a problem in the industry as the quality and thus the quantity of marketable apples is reduced.

Elongation of vegetative and reproductive structures can be stimulated by manipulating the cellular nature through application of plant growth regulators (PGRs) (Taiz and Zeiger, 2010). Cytokinin and different gibberellins (GAs) stimulate cell division and promote cell enlargement, respectively (Al-Wir, 1978; Smith et al., 1996; Wismer et al., 1995). For instance, apple fruit length was enhanced following the application of either cytokinin, GA or a combination of the two (Burak and Büyükyilmaz, 1998; Curry and Greene, 1993; McArtney, 1994). Stem elongation was stimulated in apples (Müller and Theron, 2018), carnation cut flowers (Al-Ma'athedi et al., 2018), mustard plants (Akter et al., 2007) and the Leucospermum cultivar, Soleil (Louw et al., 2018) by $GA_3$ application at different concentrations. A combination of $GA_{4+7}$ and the cytokinin, 6-benzyladenine (6-BA), was also successful in elongating 'Succession II' Leucospermum stems after five applications at 100 $mg \cdot L^{-1}$ (Louw et al., 2018). Prive et al. (1989) investigated the potential of $GA_{4+7}$ and 6-BA to increase pedicel length of 'Spartan' apples following a treatment with the growth retardant, paclobutrazol (PBZ). Both the foliar PBZ application (2000 mg·L$^{-1}$) and soil drench (10 g per tree applied in five L water) reduced the pedicel length significantly. Although 25 mg·L$^{-1}$ 6-BA, $GA_{4+7}$ and a combination of both, failed to rectify the negative effect of PBZ when applied at king flower full bloom, the higher rate of $GA_{4+7}$ at 150 mg·L$^{-1}$, two weeks before full boom, led to an increase in pedicel length relative to the PBZ-treated trees.

The aim of this study was to evaluate the efficacy of different rates and timings of $GA_{4+7}$ and the combination of $GA_{4+7}$ and 6-BA, on the pedicel elongation of apple cultivars Fuji, Nicoter and Cripps' Pink. In addition, the effect on fruit set, yield, fruit quality and return bloom was also evaluated to determine whether side-effects occurred.

## Materials and Methods

*Plant material and site description. 2017/18 and 2018/19 seasons.* During both the 2017/18 and 2018/19 seasons, trials were conducted on three different apple cultivars, viz., Nicoter, Fuji and Cripps' Pink. The trials were done on the following farms in the EGVV, South Africa: Alafontana (34°02'32.3" S, 19°06'36.5" E) in Vyeboom ('Nicoter'), Oak Valley Estate (34°10'09.1" S, 19°03'26.1" E) ('Fuji') and Applegarth (34°08'02.7" S, 19°01'44.6" E) ('Cripps' Pink') in Elgin. The trials on 'Nicoter' and 'Fuji' apples were in the same orchard in both seasons, but on different trees. The 'Cripps Pink' trials, however, were conducted in different orchards on the same farm during the two seasons. Details for each site are summarized in Table 1. Experimental trees were selected based on uniformity with regards to size and flower density.

*Experimental layout and treatments: 2017/2018 season.* Two products, $GA_{4+7}$ (Regulex®; Valent BioSciences Corporation, Libertyville, Illinois 60048, USA) and $GA_{4+7}$ + 6-BA (Promalin®; Valent BioSciences Corporation, Libertyville, Illinois 60048, USA), were evaluated on the three cultivars. The same seven treatments as summarized in Table 2 were used for all three cultivars. A randomized complete block design (RCBD) was used with ten single tree replicates in the 'Fuji' and 'Cripps' Pink' trials and seven in the 'Nicoter' trial.

*Experimental layout and treatments: 2018/2019 season.* The PGR, $GA_{4+7}$ (Regulex®; Valent BioSciences Corporation, Libertyville, Illinois 60048, USA) was evaluated on the three cultivars. The nine treatments are summarized in Table 3. The experimental design used was a RCBD consisting of ten single tree replicates.

*Treatment application: 2017/18 and 2018/2019 seasons.* All applications were done using a motorized backpack sprayer (STIHL, Pietermaritzburg, South Africa) at ±1000 $L \cdot ha^{-1}$. No surfactants were used, and drift effects were prevented by leaving at least one buffer tree between treated trees and a buffer row when more than one row was used. Weather details for the different spray periods during the two seasons are summarized in Fig. 1 – 6.

*Data collection.* The same data were recorded in all the trials. One representative branch was tagged on each side of a tree and during full bloom, the number of flower clusters was counted. Following the natural fruit drop period, fruit set was recorded by expressing the number of fruit that set per flower cluster on the two tagged branches per tree. Thereafter, hand thinning was performed according to the commercial protocol of the specific farm and the number and weight of hand-thinned fruitlets were recorded per tree. During commercial harvest, yield per tree was recorded at each harvest date. The trunk cross sectional area of each tree was also calculated by measuring the trunk circumference ±20 cm above the graft union after harvest. Subsequently, the yield efficiency of the individual trees was determined as kg fruit per trunk cross sectional area ($kg \cdot cm^{-2}$). In 2018, 50 fruit per tree (at the main harvest) and in 2019, 30 fruit per tree (at the main and second harvests) were randomly selected and taken to the laboratory at Stellenbosch University where the following were determined: the number of well-developed seeds, fruit length, -weight, -diameter, fruit defects (calyx-end ribbing, cracking and pedicel-end russeting). Pedicel-end russeting was scored on a scale of 1 to 12, with 1 being no russet and 12 severe russet (Fig. 7), and both calyx-end ribbing and cracking were monitored as present or absent (Fig. 8). In addition, the pedicels were removed with a needle nose plier and the length (from the point of entry into the fruit to the abscission zone), weight and diameter (just below the swollen area of the abscission zone), were measured. A GÜSS texture analyzer (Guss electronic model GS 20, Strand, South Africa) was used for all apple weight and -diameter recordings. All length and pedicel diameter measurements were done with an electronic micrometer caliper (Mitutoyo 500, Illinois, USA) and pedicel weight was measured with an electronic precision balance (Kern EWJ, Stuttgart, Germany). During the following seasons, return bloom was recorded on the two tagged branches per tree used to determine fruit set previously. This was done by expressing the reproductive buds as a percentage of the total number of buds (reproductive and vegetative) on a branch. Additional data recorded during the 2018/2019 season included the number of fruit that dropped during harvest.

*Statistical analysis.* The data were analyzed using SAS Enterprise guide 7.1 (SAS Institute Inc., Cary, North Carolina, USA) using the linear model procedure and the pairwise t-test to determine the Least Significant Difference (LSD) when the F-statistic indicated significance at $P<0.05$. Single degree of freedom, orthogonal, polynomial contrasts were fitted where applicable, with linear and quadratic contrasts in the second season fitted to the three rates of the single and double $GA_{4+7}$ treatment (50, 100 and 200 $mg \cdot L^{-1}$).

## Results

*Results for the 2017/2018 season: 'Nicoter'.* No significant differences were found in the average pedicel length, but it increased linearly with the $GA_{4+7}$ rate (Table 4). Although the average pedicel diameter of $GA_{4+7}$ treated trees decreased linearly with the rate applied, with only $GA_{4+7}$ 20 $mg \cdot L^{-1}$ significantly thinner than the control, it was on average thicker than on the $GA_{4+7}$ + 6-BA treated trees (p=<.0001). Increasing the $GA_{4+7}$ + 6-BA rate led to a quadratic change in pedicel diameter with all the rates significantly reducing the diameter compared to the control and the highest rate (20 $mg \cdot L^{-1}$) being the overall thinnest, while 5 and 10 $mg \cdot L^{-1}$ did not differ from each other (Table 4). The average pedicel weight increased quadratically with the $GA_{4+7}$ rate, with $GA_{4+7}$ 10 $mg \cdot L^{-1}$ having the highest weight of the $GA_{4+7}$ treatments and being significantly heavier than the control (Table 4). Positive correlations were found between the pedicel length and the apple length, -diameter, -weight and pedicel weight (Table 5). Pedicel length explained 17%, 13%, 15% and 10% of the apple length, -diameter, -weight and pedicel weight, respectively (Table 5). Also, a negative correlation was found between the pedicel length and diameter with only 9% of the pedicel diameter being explained by the pedicel length (Table 5).

None of the treatments had a significant effect on the average fruit set per cluster on the two tagged branches (Table 6). Overall, the chemical treatments reduced the average number of fruitlets that had to be thinned by hand compared to the untreated control (p=0.0246). While both the low and intermediate $GA_{4+7}$ rates (5 $mg \cdot L^{-1}$ and 10 $mg \cdot L^{-1}$) significantly reduced the number of thinned fruitlets compared to the control, the highest rate (20 $mg \cdot L^{-1}$) had no effect (Table 6). An increasing rate of the combination of $GA_{4+7}$ and 6-BA led to a linear decrease in the number of hand-thinned fruitlets with only the highest rate (20 $mg \cdot L^{-1}$) having significantly fewer fruitlets thinned than the control (Table 6). Overall, no significant differences were found in the average fruit size (weight, length and diameter) at commercial harvest (Table 7). However, the average fruit weight and diameter was significantly higher on trees treated with $GA_{4+7}$ + 6-BA compared to those treated with $GA_{4+7}$ alone. Also, the average fruit length increased linearly with the $GA_{4+7}$ + 6-BA rate (Table 7).

All the trees that received PGR treatments had a significantly higher percentage of fruit with calyx-end ribbing than the untreated control trees (Table 8). Calyx-end ribbing was higher in all the $GA_{4+7}$ and $GA_{4+7}$ + 6-BA treatments compared to the untreated control and increased quadratically with $GA_{4+7}$ + 6-BA rate. All the PGR treatments, except for 10 and 20 $mg{\cdot}L^{-1}$ $GA_{4+7}$ + 6-BA, increased pedicel-end cracking compared to the control. Generally, $GA_{4+7}$ resulted in more cracking than applications of the $GA_{4+7}$ + 6-BA combination. An increase in $GA_{4+7}$ and $GA_{4+7}$ + 6-BA rate resulted in a quadratic decrease in the percentage fruit with pedicel-end cracks (Table 8). Data on well-developed seeds and pedicel-end russeting are not shown due to very low and non-significant results. None of the treatments affected the total yield per tree, yield efficiency and the percentage return bloom on the two tagged branches although a negative quadratic trend was found with the $GA_{4+7}$ rate on total yield and yield efficiency per tree with the middle $GA_{4+7}$ rate (10 $mg{\cdot}L^{-1}$) having the lowest value of the three different rates (Table 9).

*'Fuji'*. The average pedicel length was significantly increased by all the treatments compared to the control (Table 10). An increase in the rate of the $GA_{4+7}$ and $GA_{4+7}$ + 6-BA treatments led to a linear increase in the pedicel length. The $GA_{4+7}$ treated fruit had thinner and lighter pedicels compared to the $GA_{4+7}$ + 6-BA treated fruit (Table 10). Increasing the $GA_{4+7}$ rate led to a quadratic decrease in the average pedicel diameter up to 10 $mg{\cdot}L^{-1}$, with all the rates significantly thinner than the control. In contrast, the average pedicel diameter increased linearly with the $GA_{4+7}$ + 6-BA rate with only the low and middle rate (5 $mg{\cdot}L^{-1}$and 10 $mg{\cdot}L^{-1}$) significantly thinner than the control. $GA_{4+7}$ affected the average pedicel weight the same as the diameter, as it also decreased quadratically with only $GA_{4+7}$ 10 $mg{\cdot}L^{-1}$ significantly lighter than the control (Table 10). The average pedicel weight was increased by all the $GA_{4+7}$ + 6-BA rates compared to the control. Positive correlations were found between the pedicel length and the apple length, -diameter, -weight and pedicel weight (Table 5). Pedicel length explained 25%, 11%, 18% and 33% of the apple length, -diameter, -weight and pedicel weight, respectively (Table 5).

None of the treatments affected the average fruit set per cluster on the two tagged branches (Table 11). No thinning data was recorded during the 2017/2018 season due to a misunderstanding with the farm. The chemical treatments reduced the average fruit weight and diameter on average compared to the untreated control (p=0.0200 and 0.0039, respectively). However, overall the average fruit size (weight, length and diameter) was not significantly affected by any of the treatments (Table 12). The combination of $GA_{4+7}$ and 6-BA increased calyx-end ribbing compared to the $GA_{4+7}$ treatments with all three the rates significantly higher than the rest of the treatments and the untreated control. Only the intermediate and high rate of $GA_{4+7}$ increased calyx-end ribbing compared to the control (Table 13). No pedicel-end cracks were found during the 2017/2018 harvest and data on well-developed seeds and pedicel-end russeting are not shown due to very low and non-significant results. No differences were found in the total yield per tree and yield efficiency (Table 13). The percentage return bloom on the two tagged branches decreased linearly with increasing rate of $GA_{4+7}$ + 6-BA, and $GA_{4+7}$ (p=0.0505), but overall was not reduced in comparison to the untreated control.

*'Cripps' Pink'*. While none of the $GA_{4+7}$ treatments altered the average pedicel length, it increased linearly with $GA_{4+7}$ + 6-BA rate with only the highest rate (20 $mg \cdot L^{-1}$) significantly longer than the rest of the treatments and the control (Table 14). All the treatments resulted in thicker and heavier pedicels compared to the control (Table 14). An increase in $GA_{4+7}$ rate led to a quadratic increase in the pedicel diameter and therefore the weight, with the intermediate rate (10 $mg \cdot L^{-1}$) having the highest average diameter and weight of the three rates (Table 14). Increasing $GA_{4+7}$ + 6-BA rate led to a linear decrease in the average pedicel diameter and increase in weight (Table 14). On average, the average pedicel diameter was higher in the $GA_{4+7}$ treated trees than the $GA_{4+7}$ + 6-BA treated trees, but the opposite was found with the average pedicel weight. While a negative correlation was found between the pedicel length and the apple weight, pedicel length correlated positively with the pedicel weight. Pedicel length explained 4% and 19% of the apple weight and pedicel weight, respectively (Table 5).

All the treatments, except the lowest rate of $GA_{4+7}$ (5 $mg \cdot L^{-1}$), significantly reduced the average fruit set per cluster on the two tagged branches compared to the control (Table 15). The $GA_{4+7}$ + 6-BA treatments led to a more severe reduction in the fruit set compared to the $GA_{4+7}$ treatments. The latter result were reflected in the average number of fruitlets that needed to be hand thinned per tree as it decreased linearly with the $GA_{4+7}$ + 6-BA rate, with the highest rate (20 mg·L$^{-1}$) significantly lower than the untreated control and all the other treatments, except 5 mg·L$^{-1}$ $GA_{4+7}$ (Table 15). The rest of the treatments had no effect on the hand thinning requirement. None of the treatments affected the average fruit weight and length at harvest. On average, chemical treatments increased fruit diameter compared to the control (Table 16). Treating trees with $GA_{4+7}$ + 6-BA increased average fruit diameter more than $GA_{4+7}$ treatments ($p=<.0001$). While none of the $GA_{4+7}$ treatments differed significantly from each other or from the control, the average fruit diameter increased quadratically with increasing $GA_{4+7}$ + 6-BA rate with the intermediate and high rates (10 mg·L$^{-1}$ and 20 mg·L$^{-1}$) significantly higher than the untreated control (Table 16).

The percentage fruit with calyx-end ribbing was not affected by any of the treatments (Table 17). No pedicel-end cracks were found during the 2017/2018 season and data on well-developed seeds and pedicel-end russeting are not shown due to very low and non-significant results. The total yield and yield efficiency per tree decreased linearly with the $GA_{4+7}$ + 6-BA rate with the highest rate (20 mg·L$^{-1}$) severely reducing yield and yield efficiency compared to the rest of the treatments and the control (Table 17). No significant differences were found among the rest of the treatments and the control. Percentage return bloom on the two tagged branches was not affected by the treatments, but did decrease linearly with increasing $GA_{4+7}$ + 6-BA rate (Table 17).

*Results for the 2018/2019 season: 'Nicoter'.* On average, the double $GA_{4+7}$ applications resulted in longer, but thinner and lighter pedicels compared to the single $GA_{4+7}$ application. The average pedicel length was increased by a single $GA_{4+7}$ application at 200 mg·L$^{-1}$ as well as double $GA_{4+7}$ applications at 50, 100 and 200 mg·L$^{-1}$ compared to the control (Table 18). Also, the three double $GA_{4+7}$ treatments had the longest pedicels amongst all the treatments except the for the double application at 50 mg·L$^{-1}$ that did not differ from the single applications at 100 and 200 mg·L$^{-1}$. The average pedicel diameter was reduced by all $GA_{4+7}$ applications except for single applications at 100 and 200 mg·L$^{-1}$. Also, pedicel diameter decreased quadratically with the double $GA_{4+7}$ rate, with no decrease from 50 to 100 mg·L$^{-1}$, but a significant decrease from 100 to 200 mg·L$^{-1}$ (Table 18). With double $GA_{4+7}$ applications, there was no difference in the average pedicel weight from 50 to 100 mg·L$^{-1}$, but a significant decrease from 100 to 200 mg·L$^{-1}$ which gave rise to a quadratic trend (Table 18). The average pedicel weight was significantly lower with the double

$GA_{4+7}$ applications at 20, 50, and 200 mg·L$^{-1}$ and the four 10 mg·L$^{-1}$ $GA_{4+7}$ applications compared to the single $GA_{4+7}$ application, double $GA_{4+7}$ at 100 mg·L$^{-1}$ and the untreated control. Positive correlations were found between the pedicel length and the apple length, -diameter and -weight (Table 5). Pedicel length explained 33%, 20% and 27% of the apple length, -diameter and -weight, respectively (Table 5). The effect of treatments on pedicel size is illustrated in Fig. 9A.

Both the average fruit set per cluster on the two tagged branches and the number of hand-thinned fruitlets per tree were on average reduced by the PGR treatments (p=0.0127 and 0.0011, respectively) (Table 19). Of the three single $GA_{4+7}$ treatments, only the highest rate significantly reduced the average fruit set per cluster compared to the control. An increase in the double $GA_{4+7}$ rate led to a quadratic decrease in the average fruit set, with 100 and 200 mg·L$^{-1}$ not significantly different from each other but significantly lower than the control (Table 19). Increasing rates of both the single and double $GA_{4+7}$ treatments led to a linear decrease in the number of fruitlets that had to be hand thinned per tree with both single and double applications at 100 and 200 mg·L$^{-1}$ $GA_{4+7}$ significantly lower than the control. $GA_{4+7}$ at 10 mg·L$^{-1}$, applied four times, significantly reduced fruit set and hand thinning requirement compared to the control (Table 19).

The average fruit size at commercial harvest (weight, length and diameter) increased linearly with the rate of both the single and double $GA_{4+7}$ applications (Table 20). Only the highest single $GA_{4+7}$ rate (200 mg·L$^{-1}$) significantly increased the average fruit weight, length and diameter compared to the control (Table 20). While, in terms of double applications, only 200 mg·L$^{-1}$ $GA_{4+7}$ increased the average fruit weight compared to the control, the average fruit length was increased at both 100 and 200 mg·L$^{-1}$ (Table 20). The average fruit diameter was significantly increased by all three double $GA_{4+7}$ application treatments with 200 mg·L$^{-1}$ having the overall greatest effect.

All the double $GA_{4+7}$ applications, except at 20 mg·L$^{-1}$, and the single applications at 100 and 200 mg·L$^{-1}$ resulted in more calyx-end ribbing compared to the control (Table 21). The percentage fruit with calyx-end ribbing was on average higher in response to double compared to single $GA_{4+7}$ applications (Table 21). Calyx-end ribbing increased linearly with increasing $GA_{4+7}$ rate. No pedicel-end cracks were found and an unexplainable quadratic trend with the single $GA_{4+7}$ rate was found in the fruit that dropped during harvest, while none of the treatments affected it (Table 21). Data on well-developed seeds and pedicel-end russeting are not shown due to very low and non-significant results.

The total yield per tree decreased linearly with increasing $GA_{4+7}$ application rate (50, 100 and 200 mg·L$^{-1}$). Double $GA_{4+7}$ applications at 100 mg·L$^{-1}$ and 200 mg·L$^{-1}$, and a single $GA_{4+7}$ at 200 mg·L$^{-1}$ resulted in significantly lower yields per tree compared to the control (Table 22). The highest rate of $GA_{4+7}$ resulted in the lowest yield. Yield efficiency decreased linearly with the rate of double $GA_{4+7}$ applications (Table 22). None of the treatments affected the percentage return bloom on the two tagged branches (Table 22).

*'Fuji'*. Increasing the rate of single and double $GA_{4+7}$ applications resulted in a linear increase in the average pedicel length, with double applications having a generally greater effect (p=0.0039) (Table 23). The highest rate (200 mg·L$^{-1}$) applied either once or twice and the four $GA_{4+7}$ 10 mg·L$^{-1}$ applications had the longest pedicels compared to the rest of the treatments and the untreated control. The average pedicel diameter increased linearly with rate when $GA_{4+7}$ was applied twice, but none of the treatments altered the average pedicel diameter compared to the control (Table 23). The average pedicel weight increased linearly with rate when $GA_{4+7}$ was applied once or twice and was higher than the control in all the treatments except following single $GA_{4+7}$ application at 50 mg·L$^{-1}$ and two $GA_{4+7}$ applications at 100 mg·L$^{-1}$ (Table 23). Positive correlations were found between the pedicel length and the apple length, -diameter, -weight and pedicel weight (Table 5). Pedicel length explained 19%, 16%, 17% and 35% of the apple length, -diameter, -weight and pedicel weight, respectively (Table 5). The effect of treatments on pedicel size is illustrated in Fig. 9B.

No significant differences were found in the average fruit set per cluster on the two tagged branches, nor in the number of fruitlets that needed to be hand thinned per tree (Table 24). Trees that received a single $GA_{4+7}$ application had larger fruit (weight, length and diameter) on average compared to the trees that received double $GA_{4+7}$ applications (Table 25). Average fruit weight and diameter was significantly increased by two $GA_{4+7}$ applications at 20 mg·L$^{-1}$ compared to all treatments except the single 200 mg·L$^{-1}$ application. None of the treatments altered the average fruit length (Table 25).

The percentage fruit with calyx-end ribbing increased linearly with increasing rate of a single $GA_{4+7}$ application, with 100 and 200 mg·L$^{-1}$ inducing significantly more ribbing compared to the control (Table 26). The double $GA_{4+7}$ applications at 50, 100 and 200 mg·L$^{-1}$ and the four 10 mg·L$^{-1}$ $GA_{4+7}$ applications also increased calyx-end ribbing compared to the control. Although treatments did not differ significantly, $GA_{4+7}$ applications (p=0.0183) on average reduced the fruit that dropped during harvest. Single $GA_{4+7}$ applications on average reduced drop more compared to the double $GA_{4+7}$ applications (p=0.0093) (Table 26). No pedicel-end cracks were found during the 2018/2019 harvest and data on well-developed seeds and pedicel-end russeting are not shown due to very low and non-significant results. None of the treatments had a significant effect on the total yield or yield efficiency per tree (Table 27). Treatments did not differ significantly but the percentage return bloom decreased linearly with an increase in rate of double $GA_{4+7}$ applications. None of the individual treatments altered the return bloom percentage (Table 27).

*'Cripps' Pink'*. On average, the double 50, 100 and 200 $mg{\cdot}L^{-1}$ $GA_{4+7}$ treatments induced longer and thinner, but heavier pedicels than the single $GA_{4+7}$ applications (Table 28). The average pedicel length increased linearly with increasing rate of $GA_{4+7}$ applied and all the rates except the single 50 $mg{\cdot}L^{-1}$ $GA_{4+7}$ application had longer pedicels compared to the control (Table 28). The two $GA_{4+7}$ 200 $mg{\cdot}L^{-1}$ applications had significantly longer pedicels than all other treatments. Increasing the rate of a single $GA_{4+7}$ application decreased pedicel diameter linearly with the highest rate together with all the double $GA_{4+7}$ rates and the four 10 $mg{\cdot}L^{-1}$ $GA_{4+7}$ treatment having significantly thinner pedicels compared to the control (Table 28). The average pedicel weight was significantly reduced compared to the control by the single 50 and 100 $mg{\cdot}L^{-1}$ $GA_{4+7}$ applications (Table 28). In contrast, the pedicel weight increased quadratically with increasing rate of two $GA_{4+7}$ applications with 20, 100 and 200 $mg{\cdot}L^{-1}$ developing significantly heavier pedicels compared to the control. Positive correlations were found between the pedicel length and the apple length, -weight and pedicel weight (Table 5). Pedicel length explained 20%, 7% and 23% of the apple length, -weight and pedicel weight, respectively (Table 5). The effect on pedicel size is illustrated in Fig. 9C.

On average, fruit set and hand thinning requirement was reduced in trees treated with two $GA_{4+7}$ applications compared to a single $GA_{4+7}$ application (Table 29). All the treatments, except the single 50 $mg{\cdot}L^{-1}$ $GA_{4+7}$ application reduced the average fruit set per cluster on the two tagged branches compared to the control (Table 29). Both fruit set and number of fruitlets that needed to be thinned by hand decreased linearly with increasing rate of double $GA_{4+7}$ applications. The least hand thinning was required on trees treated twice with 200 $mg{\cdot}L^{-1}$ (Table 29). None of the other treatments significantly affected the average number of hand thinned fruitlets compared to the control.

None of the treatments affected the average fruit weight and diameter (Table 30). The average fruit weight was, however, on average increased by the $GA_{4+7}$ treatments compared to the untreated control (p=0.0402). The average fruit length was on average longer following double $GA_{4+7}$ applications compared to a single application (Table 30). The fruit length increased linearly with increasing rate of double $GA_{4+7}$ application and was higher following double 50, 100 and 200 $mg \cdot L^{-1}$ applications compared to the control. In addition, the single $GA_{4+7}$ 100 $mg \cdot L^{-1}$ application and the four 10 $mg \cdot L^{-1}$ $GA_{4+7}$ applications increased the average fruit length at commercial harvest compared to the control.

The percentage fruit with calyx-end ribbing and the fruit that dropped during harvest were not affected by any of the treatments (Table 31). No pedicel-end cracks were found during the 2018/2019 harvest and data on well-developed seeds and pedicel-end russeting are not shown due to very low and insignificant results. On average, the total yield and yield efficiency per tree decreased more with the double $GA_{4+7}$ applications than with the single $GA_{4+7}$ treatment (Table 32). None of the single $GA_{4+7}$ rates affected the yield per tree and only 200 $mg \cdot L^{-1}$ significantly reduced the yield efficiency compared to the control (Table 32). Both the yield and yield efficiency per tree decreased linearly with increasing rate of $GA_{4+7}$ applied twice and were significantly lower with the double 50, 100 and 200 $mg \cdot L^{-1}$ $GA_{4+7}$ applications compared to the untreated control (Table 32). Overall, two 200 $mg \cdot L^{-1}$ $GA_{4+7}$ applications led to the lowest yield and yield efficiency. The percentage return bloom on the two tagged branches decreased linearly with increasing rate of $GA_{4+7}$ applied twice with only 200 $mg \cdot L^{-1}$ significantly lower than the control (Table 32).

## Discussion

*2017/2018 season.* During the first season, the average pedicel length of ‘Cripps’ Pink’ apples was slightly increased by 20 $mg \cdot L^{-1}$ $GA_{4+7}$ + 6-BA applied three times (pink bud, 7 and 14 days after pink bud (d.a.p.b.)) compared to the control. Overall, the pedicel diameter was lower with the $GA_{4+7}$ + 6-BA treatment and decreased linearly with increasing rate. The average pedicel weight, however, increased linearly with increasing $GA_{4+7}$ + 6-BA rate. Although $GA_{4+7}$ on its own did not affect the pedicel length of ‘Cripps’ Pink’, both the average pedicel diameter and weight showed a significant quadratic trend up to 10 mg·L$^{-1}$. The pedicel size of 'Nicoter apples' was barely affected. No significant differences were found in the average pedicel length, but both the length and diameter increased linearly with the $GA_{4+7}$ rate, which resulted in a quadratic trend in the pedicel weight with the weight increasing significantly from 5 to 10 mg·L$^{-1}$, but not differing between 10 to 20 mg·L$^{-1}$. The combination treatment only affected the pedicel diameter by decreasing it quadratically from 10 to 20 mg·L$^{-1}$. In the 2017/2018 season, all treatments were applied at pink bud stage, 7 and 14 d.a.p.b. and a large portion of the treated trees were already at full bloom between the last two applications (personal observation). The lack of response on pedicel length could thus be due to missing the target application period as pedicel elongation stops at full bloom (Prive et al., 1988). The more pronounced effect on pedicel diameter and weight was to be expected as the pedicel diameter increases until three to four weeks after full bloom (Prive et al., 1988). In contrast, the pedicel length of 'Fuji' was improved by $GA_{4+7}$ on its own or in combination with 6-BA. Increasing rates of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA resulted in a linear increase in the average pedicel length with the highest rates and $GA_{4+7}$ + 6-BA at 10 mg·L$^{-1}$ having the longest pedicels. The combination treatment resulted in thicker pedicels than the $GA_{4+7}$ treatment and this was reflected in the average pedicel weight as $GA_{4+7}$ + 6-BA had significantly heavier pedicels compared to the $GA_{4+7}$ treatment and the untreated control. The promising effect on pedicel length were obtained due to us managing to finish the applications prior to full bloom on the 'Fuji' trees (personal observation), despite the variability in flower phenological stages during this period.

The thinning action of 6-BA (Bound et al., 1997) in the $GA_{4+7}$ + 6-BA treatment was clear in the set and hand thinning requirement of both 'Cripps' Pink' and 'Nicoter' apples. Promalin® ($GA_{4+7}$ + 6-BA) is a registered thinning agent for 'Golden Delicious', 'Granny Smith' and 'Royal Gala' apples and 80% full bloom is registered as the first application stage. In our trials, both 'Nicoter' and 'Cripps' Pink' trees had already passed full bloom when the later applications were made, while the 'Fuji' had not (personal observation). 'Nicoter' and 'Cripps' Pink' thus received more applications in the recommended thinning window of Promalin® than 'Fuji', which resulted in more severe thinning. Compared to the control, the average fruit set per cluster of 'Cripps' Pink' apples was reduced by all three $GA_{4+7}$ + 6-BA rates, while the hand thinning requirement on both 'Cripps' Pink' and 'Nicoter' apples decreased linearly with increasing rates of the $GA_{4+7}$ + 6-BA applications. Also, $GA_{4+7}$ + 6-BA at 20 mg·L$^{-1}$ over thinned both cultivars leading to the overall lowest number of fruitlets that had to be thinned by hand during the commercial hand thinning period. Benzyladenine is known to thin apple fruitlets at 8-12 mm diameter by inhibiting leaf photosynthesis (Stopar et al., 2001; Yuan and Greene, 2000), stimulating vegetative growth (Schröder and Bangerth, 2006), and increasing ethylene production which leads to abscission (Dal Cin et al., 2007). Greene and Autio (1989) found that 6-BA can thin 'McIntosh' apple flowers at rates as low as 25 $mg{\cdot}L^{-1}$. The treatments did not affect the fruit size, total yield and yield efficiency per tree and return bloom of 'Nicoter' apples. In 'Cripps' Pink', however, the thinning action was reflected in a linear decrease in the yield and yield efficiency per tree with increasing rate of the $GA_{4+7}$ + 6-BA treatment with 20 $mg{\cdot}L^{-1}$ being significantly lower than all other treatments and the control. The fruit size (diameter) of 'Cripps' Pink' apples increased from 5 to 10 $mg{\cdot}L^{-1}$ $GA_{4+7}$ + 6-BA, but did not differ between 10 and 20 $mg{\cdot}L^{-1}$ and the return bloom was not affected by any of the treatments. The combination treatment was applied during the cell division period (Bollard, 1970) and therefore the increase in fruit diameter could either be due to the stimulating effect of 6-BA on cell division, its thinning action or cell enlargement by $GA_{4+7}$ (Al Wir, 1978; Wismer et al., 1995). It is interesting to note that although Promalin® is also registered to thin apple fruitlets at the 8-10 mm diameter stage (14 d.a.f.b.), the pre-bloom applications of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA thinned 'Nicoter' and 'Cripps' Pink' flowers at rates as low as 10 $mg{\cdot}L^{-1}$. No negative side-effects were found with the pre-bloom applications, except for the over-thinning with 20 $mg{\cdot}L^{-1}$ $GA_{4+7}$ + 6-BA in 'Cripps' Pink'. It could thus be worthwhile to evaluate $GA_{4+7}$ and $GA_{4+7}$ + 6-BA as pre-bloom thinners of apples as the earlier thinning would possibly result in larger fruit. No side-effects were found on 'Fuji' apples as none of the treatments affected the average fruit set and size, total yield and yield efficiency per tree and the return bloom of the following season.

All the treatments increased calyx-end ribbing in 'Nicoter' and 'Fuji' with the ribbing being overall higher on $GA_{4+7}$ + 6-BA treated trees compared to $GA_{4+7}$ treated trees in 'Fuji' apples and increasing quadratically with the $GA_{4+7}$ + 6-BA rate up to 10 $mg{\cdot}L^{-1}$ in 'Nicoter' apples. This was possibly due to stimulated cell division and enlargement in the calyx region by cytokinin and gibberellin, respectively (Al-Wir, 1978). Curry and Greene (1993) found an increase in uneven calyx-ends on 'Red Delicious' apples following 15 $mg{\cdot}L^{-1}$ synthetic cytokinin one week after petal fall. The ribbing in our trials was classified as present even when barely visible; therefore, the increase in this malformation has no horticultural consequence. All the treatments except $GA_{4+7}$ + 6-BA at 10 and 20 $mg{\cdot}L^{-1}$ increased the percentage 'Nicoter' apples with pedicel-end cracks compared to the untreated control. $GA_{4+7}$ and, especially, $GA_{4+7}$ + 6-BA resulted in a quadratic decrease in the cracks up to 10 $mg \cdot L^{-1}$. Gibberellins $A_{4+7}$ on its own or in combination with 6-BA were found to reduce cracking by increasing the epidermal cell size and density (Eccher, 1978; Ginzberg et al., 2014). The unusual difference between the control and the lowest rates of the treatments are not readily explainable.

*2018/2019 season.* In the following season, the $GA_{4+7}$ + 6-BA treatments were omitted due to their fruit thinning effect and the $GA_{4+7}$ rates were increased following the relatively poor results in the 2017/2018 season. The EGVV experiences insufficient winter chilling, thus resulting in delayed foliation (Sagredo, 2008), which is characterized by unsynchronized bud break and therefore varying phenological stages during the bloom period (Fig. 10; North, 1995). The latter made it difficult to apply the PGRs at the intended phenological stage before full bloom in the previous season and resulted in variable pedicel sizes (Fig. 10). Therefore, the $GA_{4+7}$ treatments were also applied at an earlier stage (from tight cluster onwards) in the second season in order to assure optimal coverage of flowers at phenological stages prior to full bloom. This approach of using earlier applications is also supported by Curry and Williams (1983) who found promising results on 'Delicious' pedicel lengths following $GA_{4+7}$ + 6-BA applications at pre-pink bud, balloon and full bloom stage.

Multiple $GA_{4+7}$ applications on 'Cripps' Pink', 'Nicoter' and 'Fuji' resulted in longer average pedicels than the single $GA_{4+7}$ application due to covering a higher percentage of flowers at the right phenological stage (before full bloom). On 'Cripps' Pink' apples, increasing rates of the double $GA_{4+7}$ applications showed a linear increase in the average pedicel length with the treatments significantly different from one another and all significantly higher than the control. The two $GA_{4+7}$ applications at 200 $mg \cdot L^{-1}$ had the longest pedicels and caused a substantial shift in the average pedicel length compared to the control (Fig. 11). All the double $GA_{4+7}$ applications decreased the average pedicel diameter, which was on average thinner compared to the single $GA_{4+7}$ applications. However, double $GA_{4+7}$ applications resulted in heavier pedicels than the single $GA_{4+7}$ applications, possibly due to the longer lengths as a positive correlation was found between pedicel length and weight. The average pedicel length of 'Nicoter' apples was the highest overall with the two $GA_{4+7}$ applications at 50, 100 and 200 $mg \cdot L^{-1}$, and both the average pedicel diameter and weight showed a quadratic change with the double $GA_{4+7}$ rate, with it not differing between 50 and 100 $mg \cdot L^{-1}$, but decreasing significantly from 100 to 200 $mg \cdot L^{-1}$. Despite the promising results of the double $GA_{4+7}$ applications at higher rates on 'Cripps' Pink' and 'Nicoter', these are not the recommended treatments due to the detrimental effect on fruit set that was also reflected in the total yield per tree. On 'Cripps' Pink', increasing the rate of the two $GA_{4+7}$ applications resulted in a linear decrease in the average fruit set and hand thinning requirement, with 200 $mg \cdot L^{-1}$ being significantly lower than the control. On 'Nicoter' apples, the double $GA_{4+7}$ applications at 100 and 200 $mg \cdot L^{-1}$ caused a significant reduction in the set and number of fruitlets that had to be thinned by hand during commercial hand thinning. Although gibberellins are generally known to increase fruit set (Greene, 1989), several studies, including ours, indicate the opposite, probably due to an increase in vegetative growth (Wertheim and Webster, 2005). Shoot growth was not monitored in our trials, but was clearly stimulated in both 'Cripps' Pink' and 'Nicoter' trees following the double $GA_{4+7}$ applications (personal observation) and concurs with Atay and Koyuncu (2016) who found a decrease in fruit set and increase in shoot growth on 'Golden Delicious' apples following applications of $GA_{4+7}$ at 150 $mg \cdot L^{-1}$ in three-week intervals from 16-21 d.a.f.b. Taylor (1978) also found that 100 and 200 $mg \cdot L^{-1}$ $GA_{4+7}$ reduced fruit set and increased shoot extension on 'Golden Delicious' apples if applied at petal drop and 11 days later, but later applications (three and four weeks after petal drop) had no effect on fruit set. Quinlan and Preston (1971) described that shoot growth during the blossom period alters the equilibrium in assimilate competition between vegetative and generative growth and subsequently limits fruit set. In addition, Edgerton (1981) proposed that the reduced fruit set is due to an induced ethylene production as he found higher ethylene in 'Golden Delicious' apple shoots following a post bloom $GA_{4+7}$ 100 $mg \cdot L^{-1}$ application. The thinning effect of $GA_{4+7}$ resulted in a linear decrease in the total yield and yield efficiency per tree of the 'Cripps' Pink' apples with double $GA_{4+7}$ application at 200 $mg \cdot L^{-1}$ being the overall lowest. On 'Nicoter', the average fruit size (weight, length and diameter) increased linearly with double $GA_{4+7}$ rate with 200 $mg \cdot L^{-1}$ being significantly higher than the control. Except for the direct effect of $GA_{4+7}$ on cell enlargement, fruit size could have also been improved due to the thinning effect and decrease of fruit number, which is known to increase fruit size (De Salvador et al., 2006). However, the increase in fruit size did not compensate for the reduced fruit numbers and yield was still reduced. It is important to note that the trial sites were managed according to commercial practice and a thinning program was still followed on 'Cripps' Pink' (700 $mg \cdot L^{-1}$ carbaryl at 10 d.a.f.b.), thus possibly further contributing to the lower yield. An additional side-effect of the higher $GA_{4+7}$ rates included a linear decrease in the return bloom in 'Cripps' Pink' with increasing rates of the double $GA_{4+7}$ applications, with 200 mg·L$^{-1}$ significantly lower than the control. The inhibitory effect of $GA_{4+7}$ on flower induction is well known (Greene, 1989; Luckwill and Silva, 1979; Tromp, 1982). Greene (1989) found that a single application of 150 mg·L$^{-1}$ $GA_{4+7}$ reduced return bloom on 'McIntosh' apples when applied from six days before full bloom until 35 d.a.f.b., thus during the flower induction phase.

Fortunately, the average pedicel length of 'Cripps' Pink' did not differ between the double $GA_{4+7}$ application at 20 mg·L$^{-1}$ and the four $GA_{4+7}$ applications at 10 mg·L$^{-1}$ and both were longer than the control. These treatments are promising as both had only a small effect on fruit set and hand thinning requirement and did not negatively affect the yield, yield efficiency per tree or return bloom. As illustrated in Fig. 11, double $GA_{4+7}$ application at 20 mg·L$^{-1}$ had the largest proportion of pedicels in the average length range compared to the four $GA_{4+7}$ applications at 10 mg·L$^{-1}$. The 20 mg·L$^{-1}$ treatment also entails fewer tractor hours and lower labor cost and is therefore the recommended treatment for pedicel elongation of 'Cripps' Pink' apples. On 'Nicoter' apples, double $GA_{4+7}$ application at 50 mg·L$^{-1}$ had no effect on the fruit set, number of hand thinned fruitlets during commercial hand thinning, fruit size, the total yield and yield efficiency per tree. Although calyx-end ribbing was increased, it was very mild as indicated before and not of any concern. As the pedicel length did not differ between 50 mg·L$^{-1}$ double $GA_{4+7}$ and the higher rates and no important side-effects were found, it is the recommended rate for pedicel elongation of 'Nicoter' apples.

On 'Fuji', increasing rates of the single and double $GA_{4+7}$ applications resulted in a linear increase in the average pedicel length with the highest rate (200 mg·L$^{-1}$) and four $GA_{4+7}$ applications at 10 mg·L$^{-1}$ having the longest pedicels on average. The increase in length contributed to the average pedicel weight as it also increased linearly with increasing rate of both the single and double $GA_{4+7}$ applications. It is interesting to note that the pedicel length of 'Fuji' apples was generally longer and the fruit size (weight, length and diameter) bigger in the first season compared to the second season. This phenomenon could have possibly been due to different endogenous hormone levels between the two seasons. Although we found a positive correlation between pedicel length and fruit size, as did Eccher and Boffelli (1981) in 'Golden Delicious' apples, it is probably not causative. None of the treatments affected the fruit set, hand thinning requirement, number of fruit that dropped during harvest, yield, yield efficiency per tree and the return bloom. The only side effect was a small, but significant increase in calyx-end ribbing in all the treatments except single $GA_{4+7}$ application at 50 mg·L$^{-1}$ and double $GA_{4+7}$ application at 20 mg·L$^{-1}$. The four 10 mg·L$^{-1}$ $GA_{4+7}$ applications is thus the recommended treatment for pedicel elongation on 'Fuji' apples as it caused more pedicels to be in the average length range compared the higher rates (Fig. 12). Although the first season had longer pedicels than the second season, the average pedicel length increased more with the four 10 mg·L$^{-1}$ $GA_{4+7}$ applications (2018/2019) than the three 20 mg·L$^{-1}$ $GA_{4+7}$ applications (2017/2018) relative to the control. In addition, the increased tractor hours and labor cost with this treatment, is possibly compensated for by the cost of the significantly lower rate.

Interestingly, apple pedicel length is a greater problem in the EGVV region, with its mild winters, compared to the colder winters in the Ceres region (personal observation) and the reason for this is still unclear. As indicated by our study, GAs and 6-BA play an active role in pedicel elongation and it would be interesting to see what effect the temperature differences between Ceres and the EGVV have on endogenous hormone production during flower differentiation and thus on pedicel lengths. Trees in both the EGVV and Ceres regions are sprayed with rest breaking chemicals at bud swell, so the actual chemical application cannot be the reason for shorter pedicels in the EGVV, although rates used in EGVV are sometimes higher. It may, however, be that the period after rest breaking application is warmer in the EGVV, thus resulting in faster development until full bloom thus reducing the time for pedicel development. Higher spring temperatures may also induce lower endogenous GA levels thus resulting in shorter pedicels. Furthermore, the interaction between pedicel growth and prohexadione-calcium may also result in shorter pedicels. Prohexadione-calcium (Regalis®), a GA synthesis-inhibitor (Unrath, 1999), is often applied at the pink bud stage to control vegetative growth and can possibly reduce apple pedicel length, as was found following application of the growth retardant, paclobutrazol, on 'Spartan' apples (Prive et al., 1989).

## Conclusion

Gibberellins $A_{4+7}$ successfully increased the pedicel length of 'Nicoter', 'Fuji' and 'Cripps' Pink' apples when applied before full bloom. Also, due to the protracted bloom and unsynchronized flower phenological stages in the EGVV region, it was best to apply the $GA_{4+7}$ multiple times from tight cluster onwards to optimize the number of clusters covered during the responsive stage of development. Although pedicel lengths were significantly increased by the higher rates of $GA_{4+7}$, the lower rates (10 $mg \cdot L^{-1}$ to 50 $mg \cdot L^{-1}$) gave fewer side-effects on fruit set, yield and return bloom. According to our trials, the recommended treatments for 'Nicoter', 'Fuji' and 'Cripps' Pink' are 50 $mg \cdot L^{-1}$ $GA_{4+7}$ applied twice, 10 $mg \cdot L^{-1}$ $GA_{4+7}$ applied four times, and 20 $mg \cdot L^{-1}$ $GA_{4+7}$ applied twice, respectively. Fitting in four applications before full bloom in 'Fuji', however, might be problematic in some seasons. Pedicel dimensions varied among the treated and untreated trees indicating that intra-plant factors contribute to the inherent pedicel length at full bloom. Tree characteristics such as the flower position in the cluster (king vs. lateral) and the type of shoot bearing the inflorescence and subsequent fruit might contribute to this variability, but to what extent is still unclear.

## Literature Cited

Akter, A.A.E., M.M.Z. Islam, R. Karim, and A.H.M. Razzaque. 2007. Effect of $GA_3$ on growth and yield of mustard. Int. J. Sustain. Crop Prod. 2(2):16-20.

Al-Ma'athedi, A.F., A.J. Abbas, and H.M. Al-abdaly. 2018. Effect of growth regulators on improving productivity and quality of carnation (*Dianthus caryophyllus* L.) flowers with economic study. Ann. of Agr. Sci. 63:109-114.

Al-Wir, A.I. 1978. The influence of growth regulators on the anatomical, morphological, development and quality of apple fruits. Iowa State Univ., Ames, PhD Diss.

Atay, A.N. and F. Koyuncu. 2016. Manipulating regular bearing in 'Golden Delicious'/M9 apple trees using $GA_{4+7}$ and ethephon, Int. J. of Fruit Sci. 16(1):10-22.

Bollard, E.G. 1970. The physiology of developing fruits, p. 387-425. In A.C. Hulme (ed.) The biochemistry of fruits and their products. Academic Press, London.

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

Burak, M. and M. Büyükyilmaz. 1998. Effect of promalin on fruit shape and quality of 'Starking Delicious' apple cultivar. Acta Hort. 463:365-370.

Curry, E.A. and D.W. Greene. 1993. CPPU influences fruit quality, fruit set, return bloom and pre-harvest drop of apples. HortSci. 28(2):115-119.

Curry, E.A. and M.X. Williams. 1983. Promalin or $GA_3$ increase pedicel and fruit length and leaf size of 'Delicious' apples treated with paclobutrazol. HortSci. 18(2):214-215.

Dal Cin, V., A. Boschetti, A. Dorigoni, and A. Ramina. 2007. Benzylaminopurine application on two different apple cultivars (*Malus domestica*) displays new and unexpected fruitlet abscission features. Ann. Bot. 99:1195-1202.

De Salvador, F.R., M. Fisichella and M. Fontanari. 2006. Correlations between fruit size and fruit quality in apple trees with high and standard crop load levels. J. Fruit Ornam. Plant Res. 14:113-122.

Eccher, T. 1978. Russeting of 'Golden Delicious' apples as related to endogenous and exogenous gibberellins. Acta Hort. 80:381-385.

Eccher, T. and G. Boffelli. 1981. Effects of dose and time of application of $GA_{4+7}$ on russeting, fruit set and shape of 'Golden Delicious' apples. Scientia. Hort. 14:307-314.

Edgerton, L.J. 1981. Some effects of aminoethoxyvinylglycine, 6-benzylamino purine and gibberellins on fruit set and vegetative growth of apple. Acta Hort. 120:125-130.

Ginzberg, I., E. Fogelman, L. Rosenthal, and R.A. Stern. 2014. Maintenance of high epidermal cell density and reduced calyx-end cracking in developing 'Pink Lady' apples treated with a combination of cytokinin 6-benzyladenine and gibberellins A4+A7. Scientia. Hort. 165:324-330.

Greene, D.W. 1989. Gibberellins $A_{4+7}$ influence fruit set, fruit quality and return bloom of apples. J. Am. Soc. Hort. Sci. 114(4):619-625.

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

Habdas, H., L.S., Jankiewicz, and B. Borkowska. 1982. Changes in the anatomical structure of the apple fruitlet pedicels preceding June drop. Acta Agrobot. 35:11-23.

Kraus, E.J. and G.S. Ralston. 1916. The pollination of pomaceous fruits III. Gross vascular anatomy of the apple. Techn. Bull. Oregon Agric. Exp. Sta. 138:4-12.

Louw, E.L., G. Jacobs, and E.W. Hoffman. 2018. Application of plant growth regulators to single Leucospermum stems to extend stem length. Acta Hort. 1201:405-412.

Luckwill, L. C. and Silva, J. M. (1979). The effects of daminozide and gibberellic acid on flower initiation, growth and fruiting of apple cv. 'Golden Delicious'. J. Hort. Sci. 54:217-223.

McArtney, S.J. 1994. Exogenous gibberellin affects biennial bearing and the fruit shape of 'Braeburn' apple. New Zeal. J. Crop. Hort. 22(3):343-346.

Müller, A.M. and K.I. Theron. 2018. The use of plant growth regulators to increase apical extension growth of first-leaf apple trees. XIth International symposium on integrating canopy, rootstock and environmental physiology in orchard systems. Acta Hort. 1228:359-362.

North, M.S. 1995. New rest-breaking agents for the control of delayed foliation of apples. Acta Hort. 409:151-154.

Prive, J.P., D.C. Elfving, and J.T.A. Proctor. 1988. Pedicel characteristics of four apple cultivars. Fruit Var. J. 45(4):122-125.

Prive, J.P., D.C. Elfving, and J.T.A. Proctor. 1989. Paclobutrazol, gibberellin, and cytokinin effects on growth, development, and histology of apple pedicels and fruits. J. Amer. Soc. Hort. Sci. 114(2): 273-278.

Quinlan, J.D. and A.P. Preston. 1971. The influence of shoot competition on fruit retention and cropping of apple trees. J. Hort. Sci. 46:525-534.

Sagredo, K.X. 2008. Effect of rest-breaking and fruit thinning treatments on reproductive development in apple. Stellenbosch Univ., Stellenbosch, PhD (Agric.) Diss.

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

Smith, R.C., P.R. Matthews, P.H.D. Schunmann, and P.M. Chandler. 1996. The regulation of leaf elongation and xyloglucan endotransglycosylase by gibberellin in 'Himalaya' barley (*Hordeum vulgare* L.) J. Expt. Bot. 47(302):1395-1404.

Stopar, M., M. Resnik, and V.Z. Pongrac. 2001. Non-structural carbohydrate status and $CO_2$ exchange rate of apple fruitlets at the time of abscission influenced by shade, NAA or BA. Scientia Hort. 87:65-76.

Taiz, L., E. Zeiger. 2010. Plant physiology, 5th ed. Sinauer Associates, Sunderland, ENG.

Taylor, K. 1978. Effects of gibberellin sprays on fruit russet and tree performance of 'Golden Delicious' apple. J. of Hort. Sci. 53(3):167-169.

Tromp, J. 1982. Flower-bud formation in apple as affected by various gibberellins. J. Hort. Sci. 57:277-282.

Unrath, C.R. 1999. Prohexadione-Ca: a promising chemical for controlling vegetative growth of apples. HortSci. 34(7):1197-1200.

Wertheim, S.J. and A.D. Webster. 2005. Manipulation of growth and development by plant bioregulators, p. 267–294. In: J. Tromp, A.D. Webster, and S.J. Wertheim (Eds.). Fundamentals of temperate zone tree fruit production. Timber Press, Portland, Oregon.

Wismer, P.T., J.T.A. Proctor, and D.C. Elfving. 1995. Benzyladenine affects cell division and cell size during apple fruit thinning. J. Amer. Soc. Hort. Sci. 120(5):802-807.

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

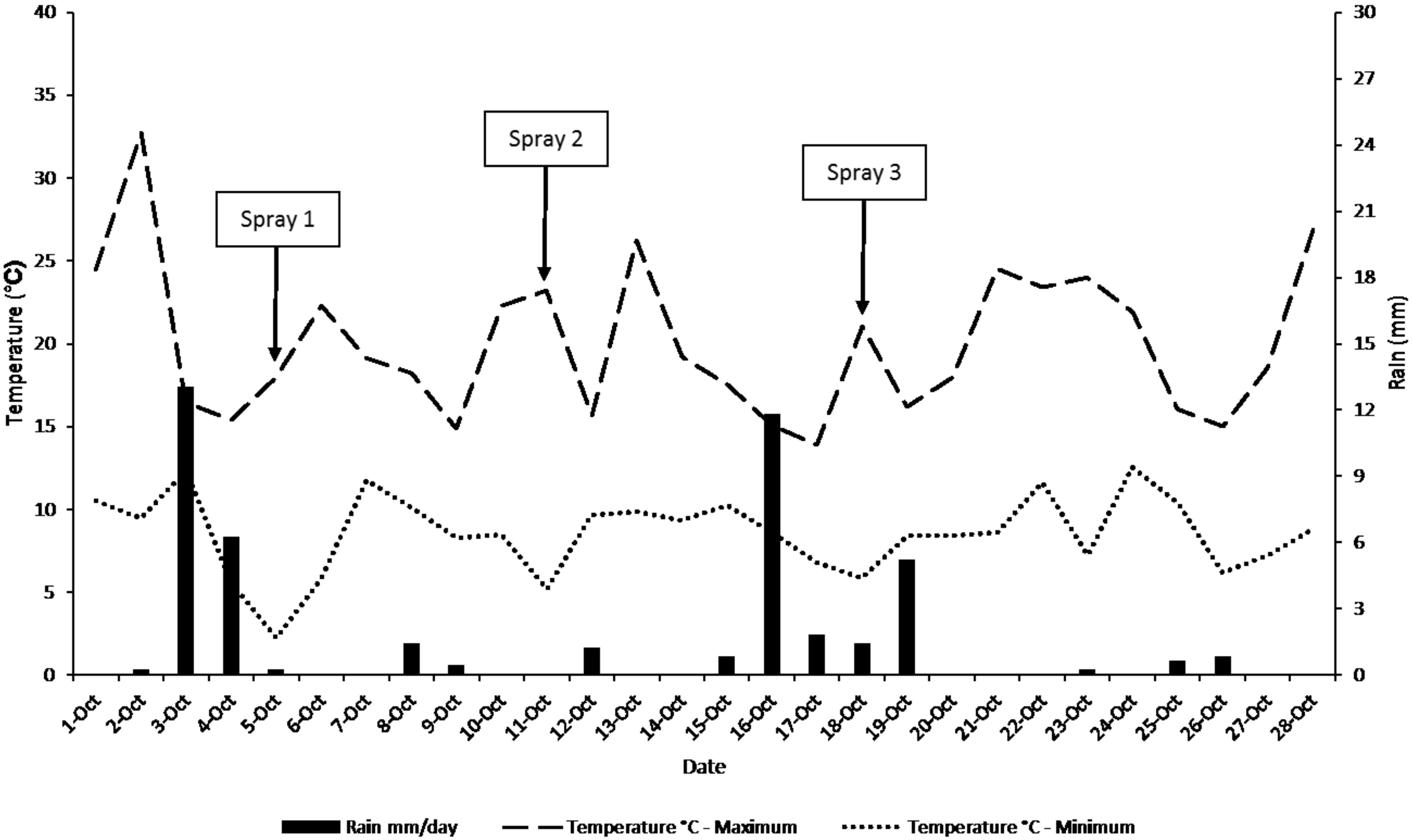


Fig. 1. Weather data for the 2017 spray period of 'Nicoter' apples at Alafontana, Vyeboom, South Africa.

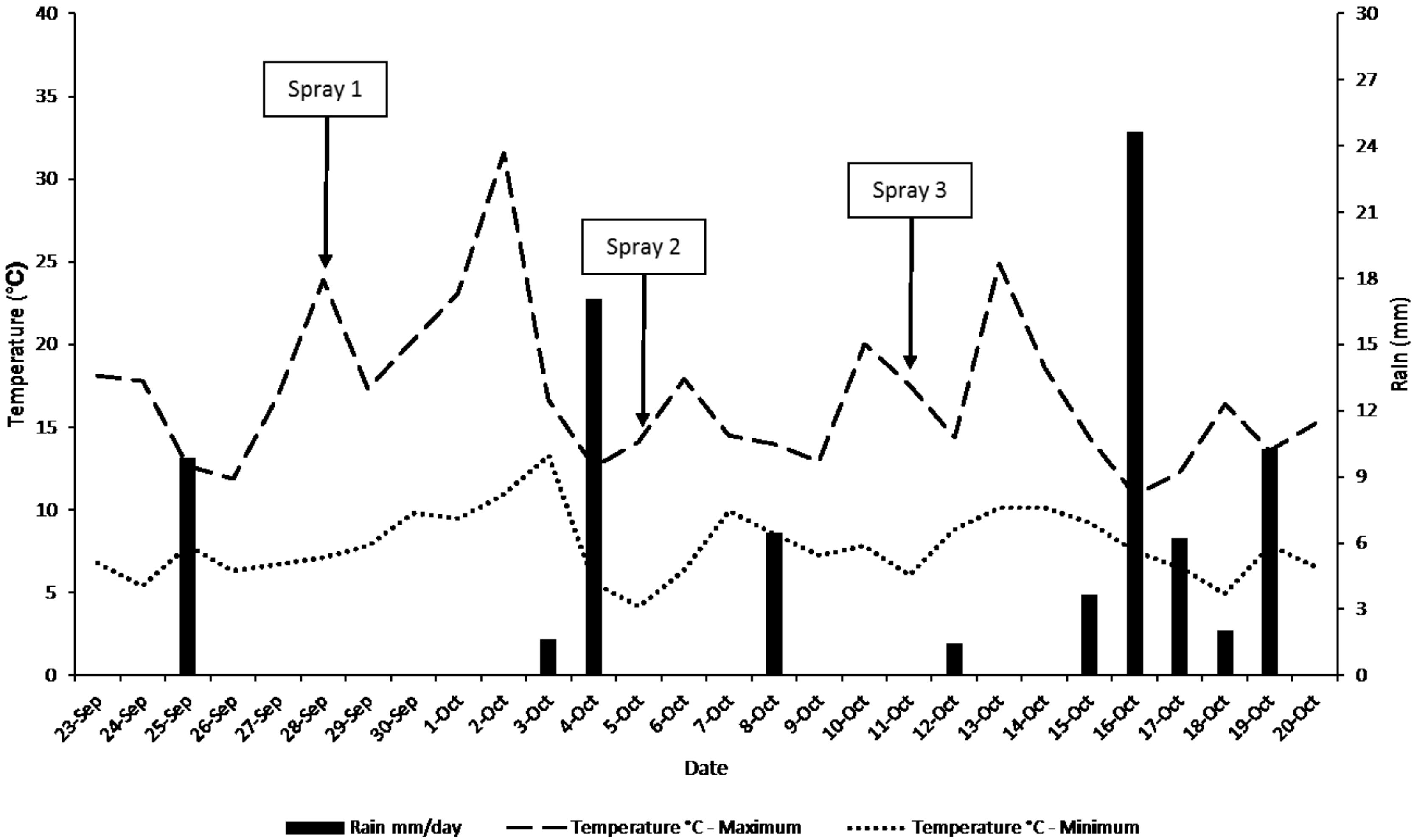


Fig. 2. Weather data for the 2017 spray period of ‘Fuji’ apples at Oak Valley, Elgin, South Africa.

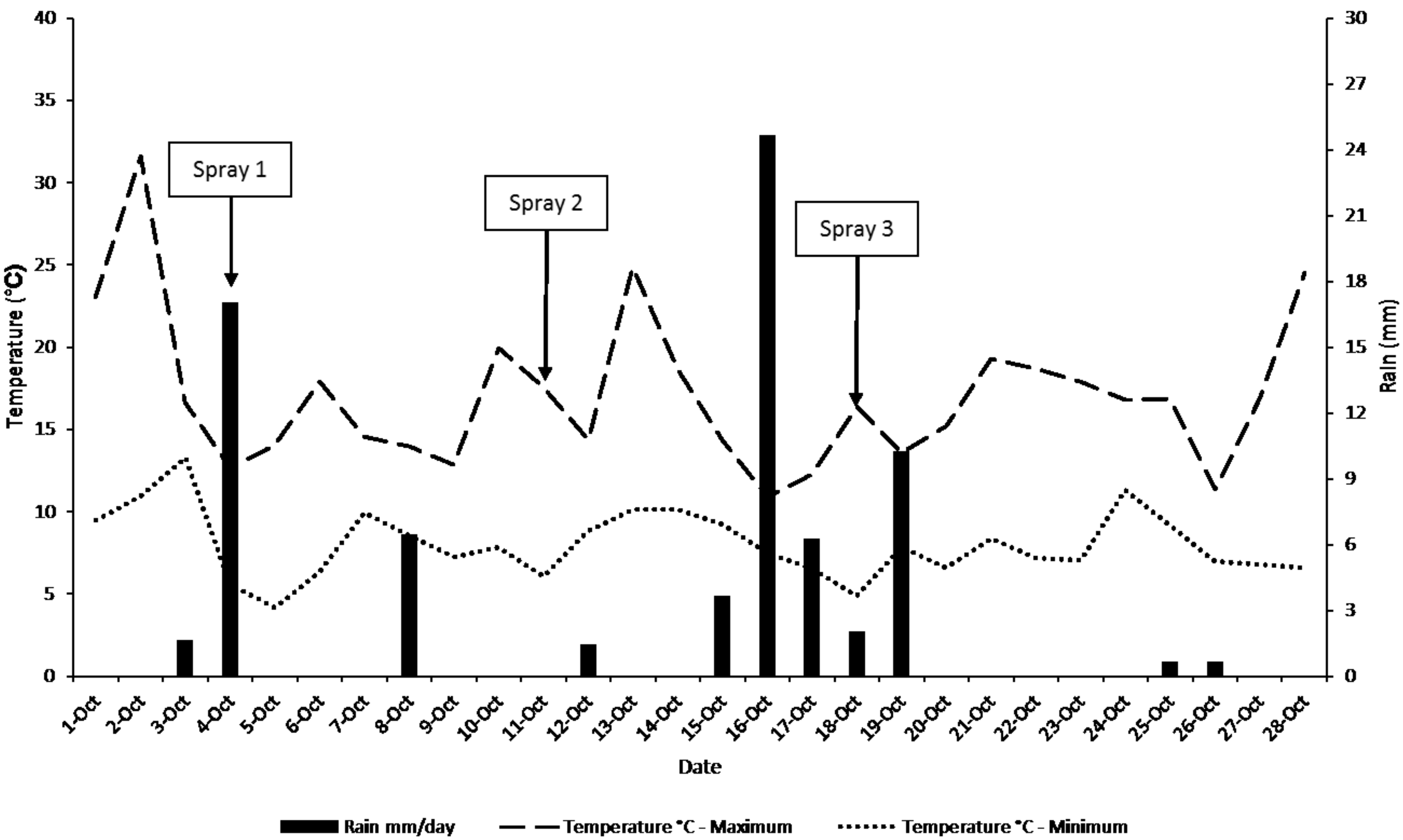


Fig. 3. Weather data for the 2017 spray period of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa.

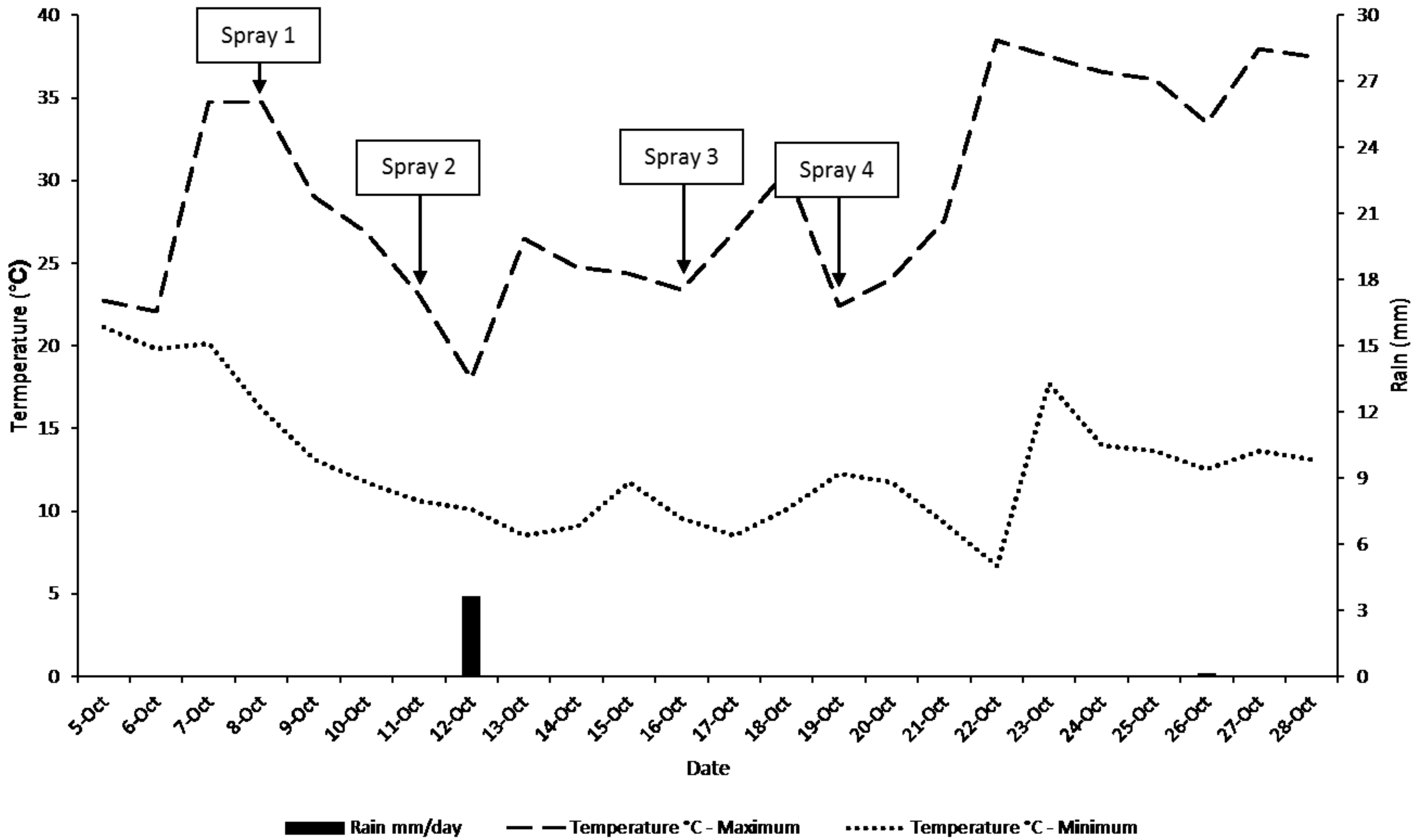


Fig. 4. Weather data for the 2018 spray period of 'Nicoter' apples at Alafontana, Vyeboom, South Africa.

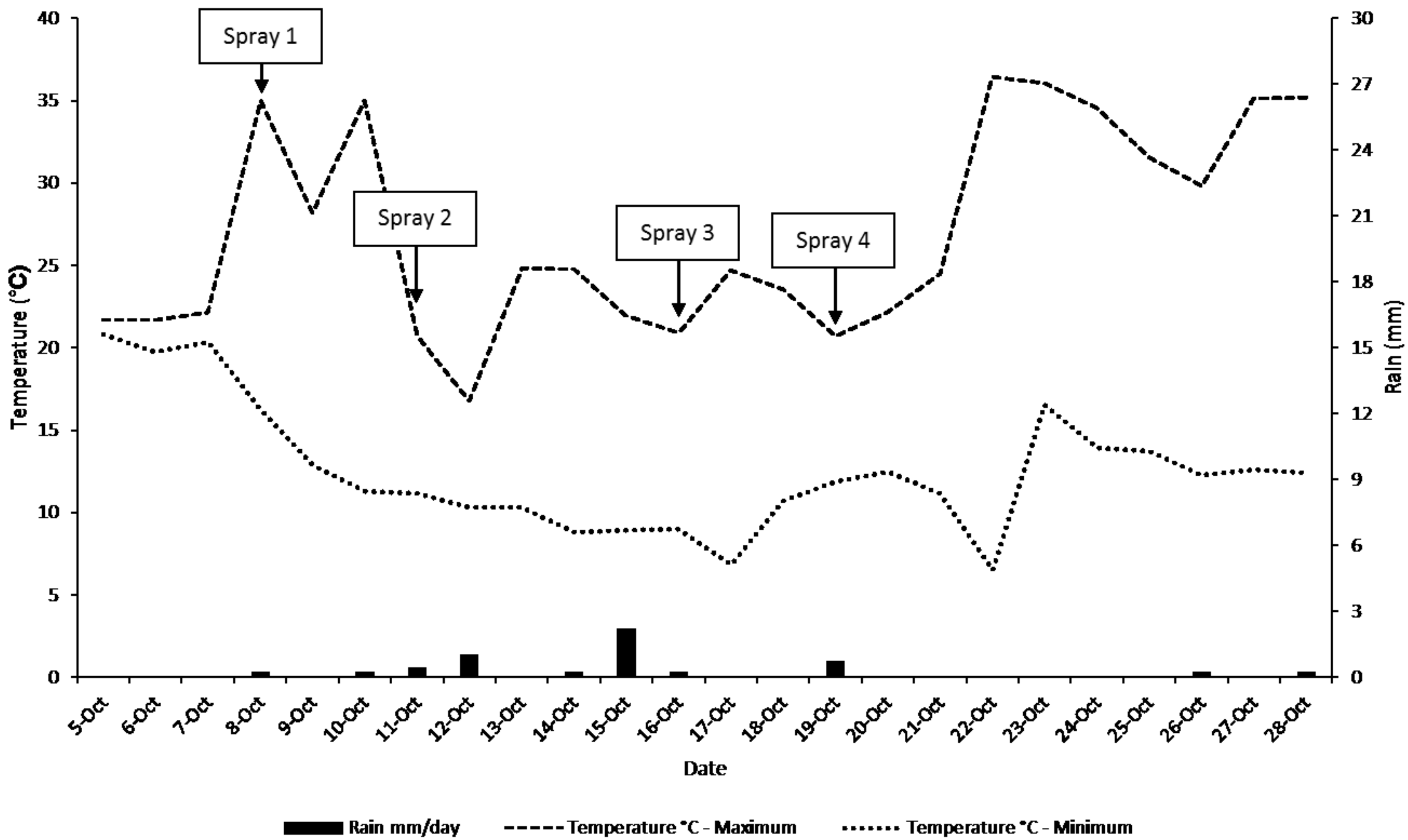


Fig. 5. Weather data for the 2018 spray period of 'Fuji' apples at Oak Valley, Elgin, South Africa.

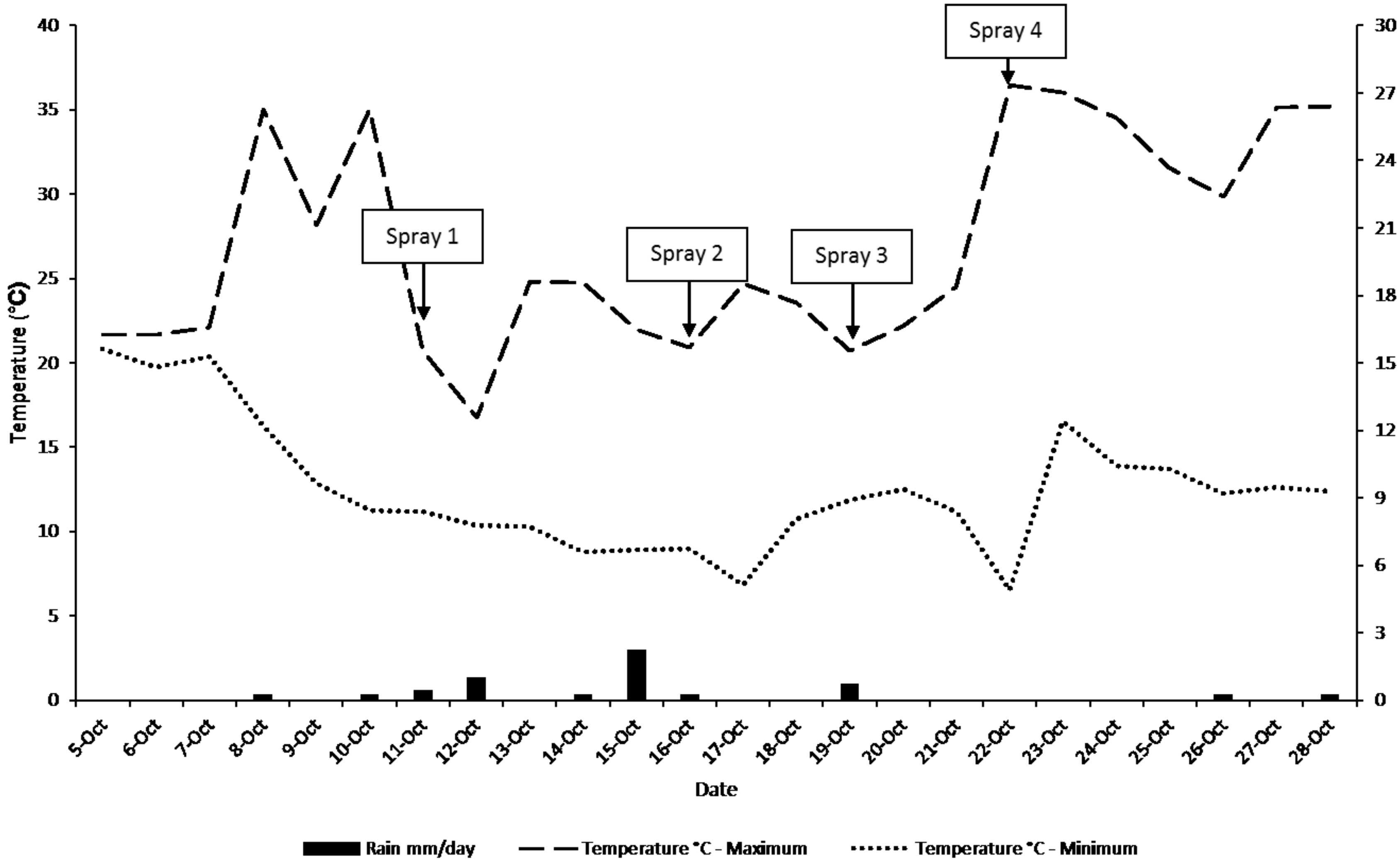


Fig. 6. Weather data for the 2018 spray period of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa.

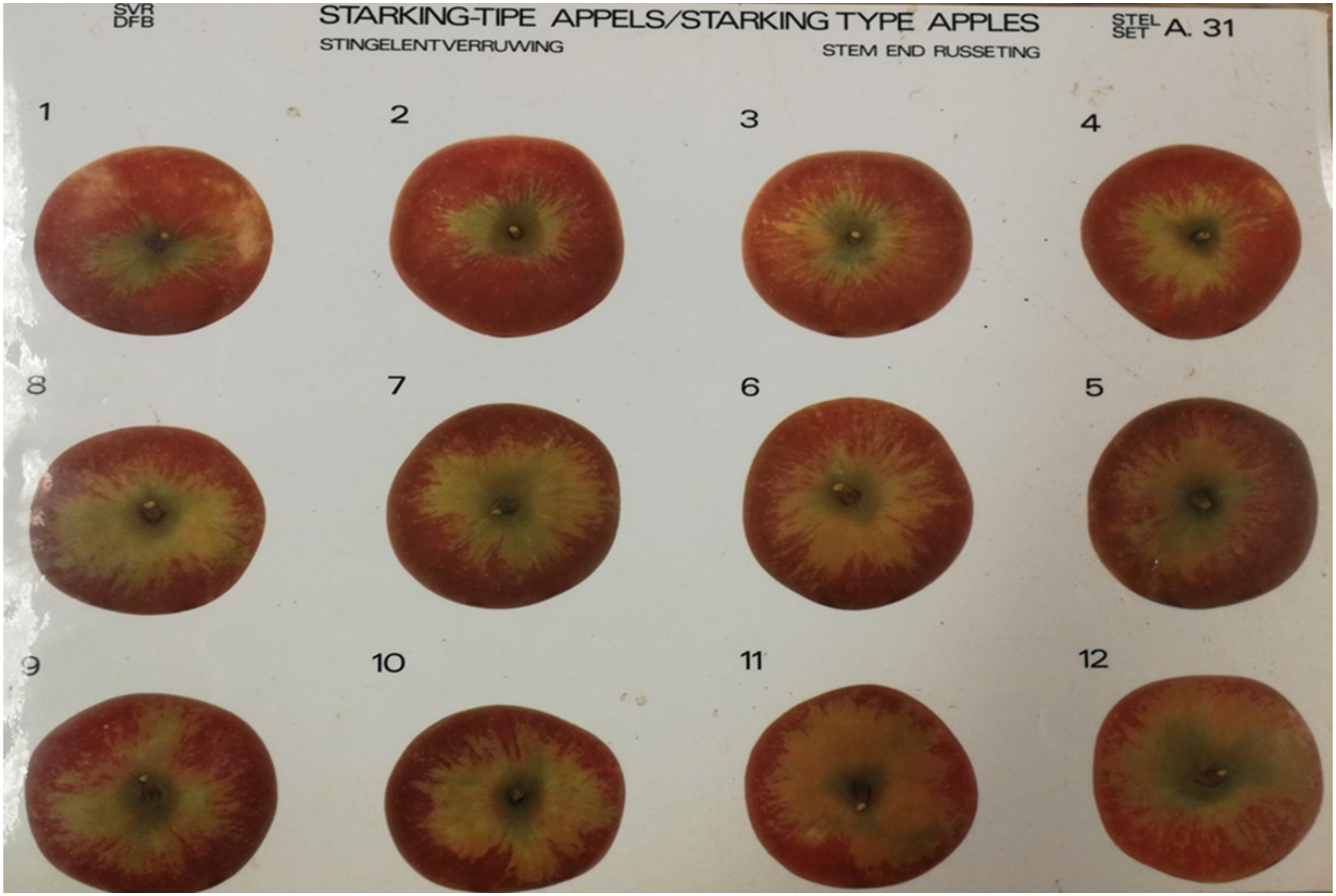


Fig. 7. Scale used for scoring of pedicel-end russeting. Deciduous Fruit Board (BFB) set A. 31.


Fig. 8. Example of an extreme form of calyx-end ribbing (1 and 2) and pedicel-end cracking (3) on 'Nicoter' apples at Alafontana, Vyeboom, South Africa.

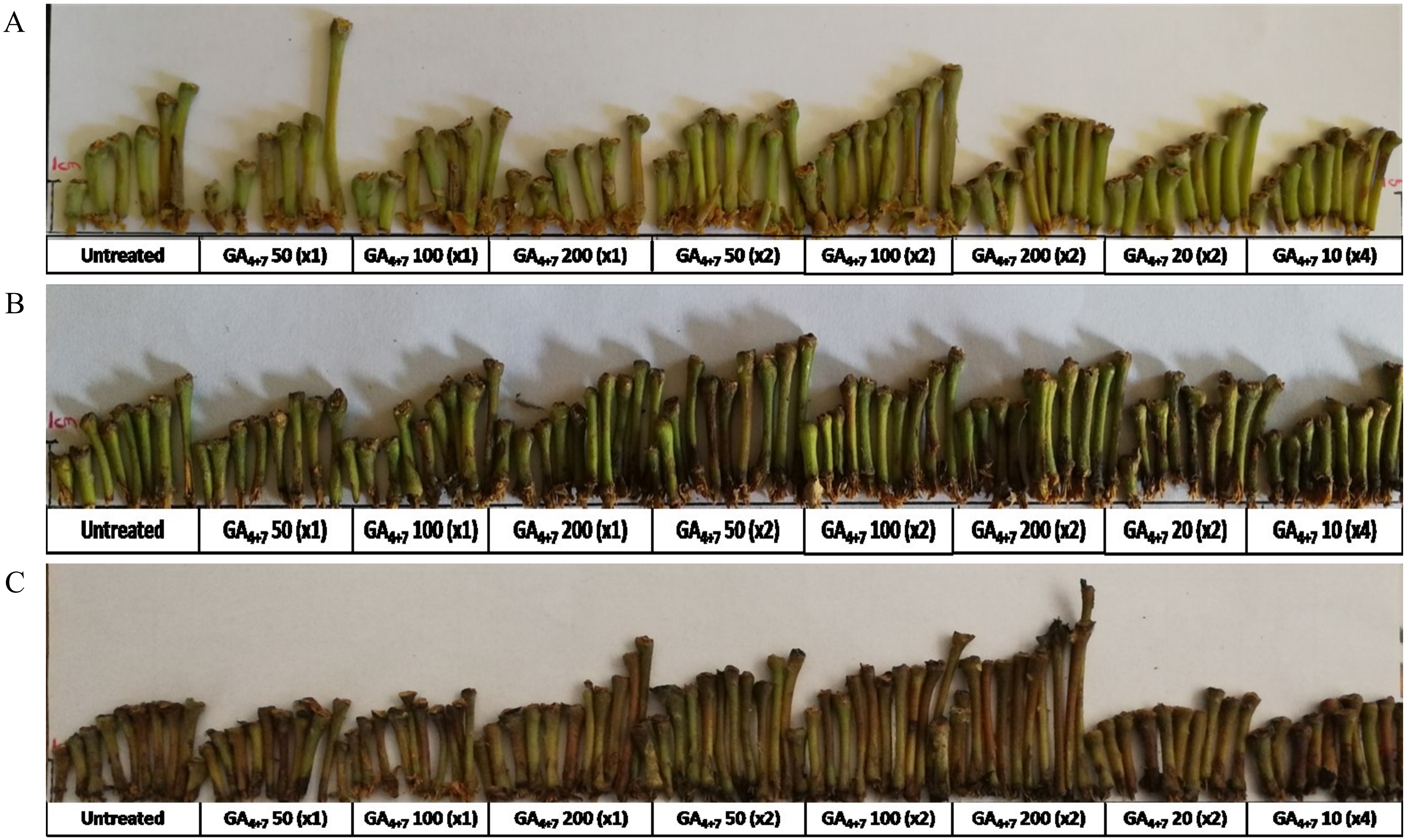


Fig. 9. Representing sample of shortest to longest pedicels in each treatment done on ‘Nicoter’(A), ‘Fuji’ (B) and ‘Cripps’ Pink’ (C) apples at Vyeboom (A) and Elgin (B and C), South Africa (2018/2019).

Fig. 10. Variable flower phenological stages and ‘Nicoter’ pedicel lengths in the 2018/2019 season.

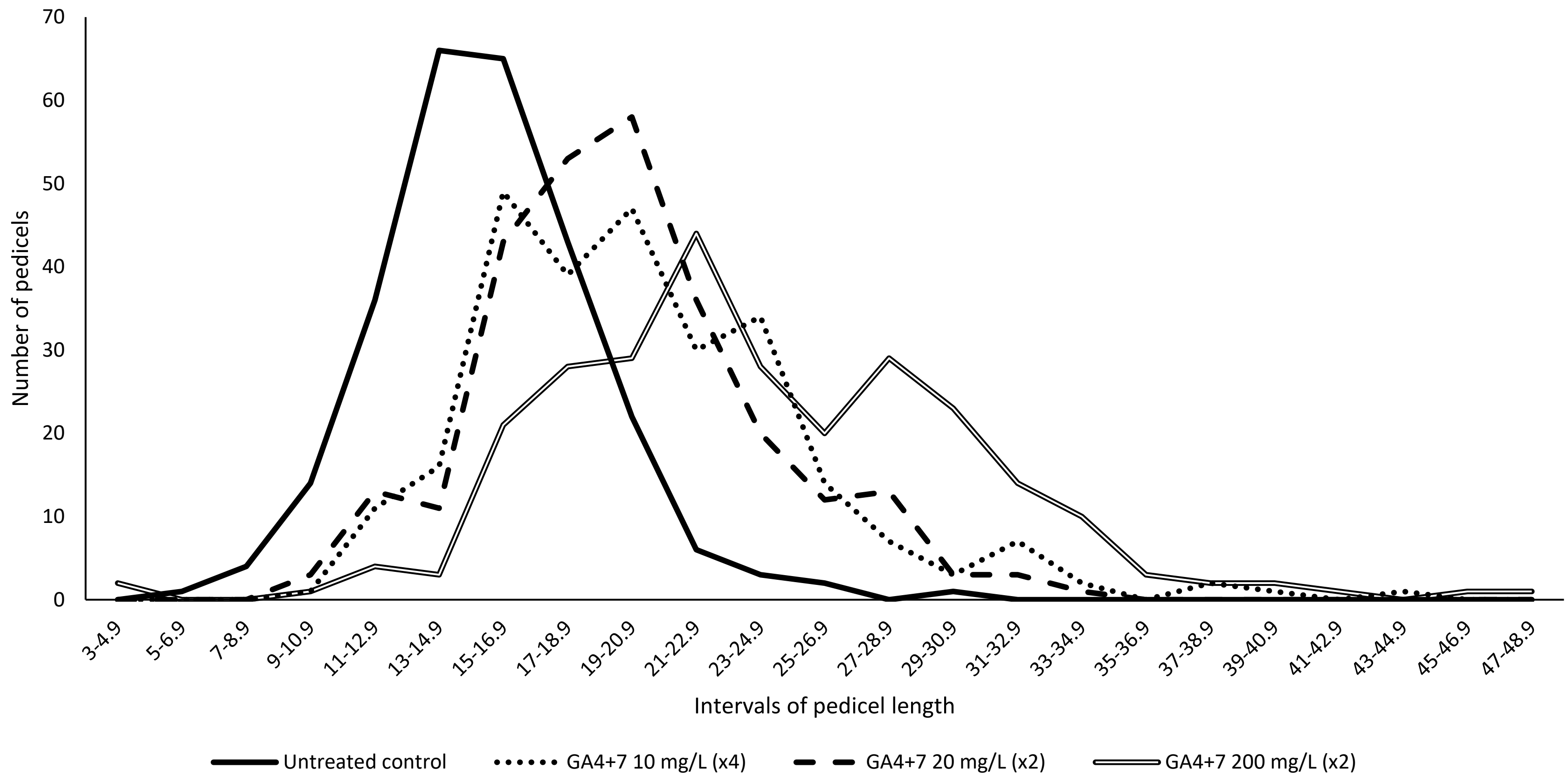


Fig. 11. Pedicel length distribution following the $GA_{4+7}$ 200 mg·L$^{-1}$ (applied twice), $GA_{4+7}$ 20 mg·L$^{-1}$ (applied twice) and $GA_{4+7}$ 10 mg·L$^{-1}$ (applied four times) treatments on ‘Cripps’ Pink’ apples at Applegarth, Elgin, South Africa (2018/2019).

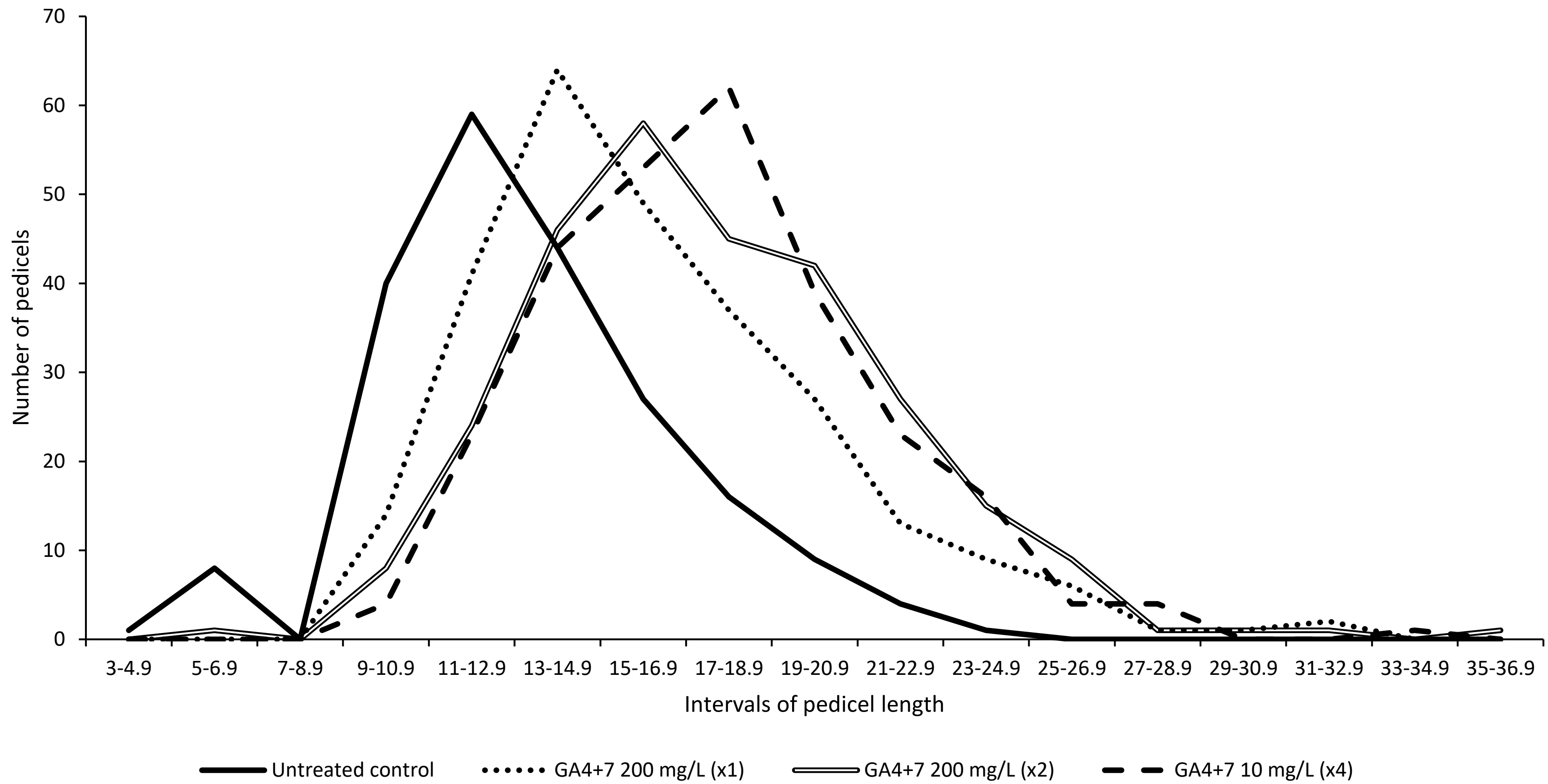


Fig. 12. Pedicel length distribution following the $GA_{4+7}$ 200 mg·L$^{-1}$ (applied once), $GA_{4+7}$ 200 mg·L$^{-1}$ (applied twice) and $GA_{4+7}$ 10 mg·L$^{-1}$ (applied four times) treatments on 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

Table 1. Orchard details for trials conducted during the 2017/2018 and 2018/2019 seasons.

| | Cultivars | | | |
|---|---|---|---|---|
| | Nicoter | Fuji | Cripps' Pink[1] | Cripps' Pink[2] |
| Site | Alafontana | Oak Valley | Applegarth | Applegarth |
| Year planted | 2011 | 2013 | 1996 | 1995 |
| Rootstock | M7 | MM109 | M793 | M7 |
| Plant/row spacing (m) | 4 x 1.25 | 4 x 1.25 | 3.5 x 1.5 | 4 x 1.5 |
| Row direction | N-S | N-S | N-S | N-S |
| % Cross pollinator trees | 10% 'Granny Smith'/ 'Braeburn' | 10% 'Granny Smith' | 50% solid row 'Fuji' | 66% solid row 'Fuji' |

[1] Details for the 'Cripps' Pink' orchard during the 2017/2018 season
[2] Details for the 'Cripps' Pink' orchard during the 2018/2019 season

Table 2. Treatment details for trials with gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on its own and in combination with 6-benzyladenine (6-BA) on three cultivars, Nicoter, Fuji and Cripps' Pink in the season of 2017/2018.

| Treatment rates* | Application times |
|---|---|
| Untreated control | |
| $GA_{4+7}$ at 5 mg·L$^{-1}$ | Pink bud, 7 dapb and 14 dapb** |
| $GA_{4+7}$ at 10 mg·L$^{-1}$ | Pink bud, 7 dapb and 14 dapb** |
| $GA_{4+7}$ at 20 mg·L$^{-1}$ | Pink bud, 7 dapb and 14 dapb** |
| $GA_{4+7}$ + 6-BA at 5 mg·L$^{-1}$[a] | Pink bud, 7 dapb and 14 dapb** |
| $GA_{4+7}$ + 6-BA at 10 mg·L$^{-1}$[b] | Pink bud, 7 dapb and 14 dapb** |
| $GA_{4+7}$ + 6-BA at 20 mg·L$^{-1}$[c] | Pink bud, 7 dapb and 14 dapb** |

* Rates of active ingredients; ** Days after pink bud; [a] 5 mg·L$^{-1}$ $GA_{4+7}$ + 5 mg·L$^{-1}$ 6-BA; [b] 10 mg·L$^{-1}$ $GA_{4+7}$ + 10 mg·L$^{-1}$ 6-BA; [c] 20 mg·L$^{-1}$ $GA_{4+7}$ + 20 mg·L$^{-1}$ 6-BA

Table 3. Treatment details for trials with gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on three cultivars, Nicoter, Fuji and Cripps' Pink in the season of 2018/2019.

| Treatment rates* | Application times |
|---|---|
| Untreated control | |
| $GA_{4+7}$ at 50 mg·L$^{-1}$ | Between Tight cluster and Pink bud stage[1] |
| $GA_{4+7}$ at 100 mg·L$^{-1}$ | Between Tight cluster and Pink bud stage[1] |
| $GA_{4+7}$ at 200 mg·L$^{-1}$ | Between Tight cluster and Pink bud stage[1] |
| $GA_{4+7}$ at 50 mg·L$^{-1}$ | Tight cluster - Pink bud stage and 3-5 days later[2] |
| $GA_{4+7}$ at 100 mg·L$^{-1}$ | Tight cluster - Pink bud stage and 3-5 days later[2] |
| $GA_{4+7}$ at 200 mg·L$^{-1}$ | Tight cluster - Pink bud stage and 3-5 days later [2] |
| $GA_{4+7}$ at 20 mg·L$^{-1}$ | Tight cluster - Pink bud stage and 3-5 days later[2] |
| $GA_{4+7}$ at 10 mg·L$^{-1}$ | Tight cluster - Pink bud stage, 3-5 days later, 3-5 days later and 3-5 days later[3] |

* Rates of active ingredients; [1] Single $GA_{4+7}$ application; [2] Two $GA_{4+7}$ applications; [3] Four $GA_{4+7}$ applications

Table 4. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on the pedicel size of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2017/2018).

| Treatment | Average pedicel length at 2018 harvest (mm) | | Average pedicel diameter at 2018 harvest (mm) | | Average pedicel weight at 2018 harvest (g) | |
|---|---|---|---|---|---|---|
| Untreated control | 13.1 | ns | 3.09 | a | 0.15 | b |
| $GA_{4+7}$ 5[a] | 12.4 | | 3.24 | a | 0.15 | b |
| $GA_{4+7}$ 10[a] | 13.3 | | 3.06 | ab | 0.18 | a |
| $GA_{4+7}$ 20[a] | 13.9 | | 2.69 | c | 0.16 | ab |
| $GA_{4+7}$ + 6-BA 5[a] | 13.0 | | 2.74 | c | 0.15 | b |
| $GA_{4+7}$ + 6-BA 10[a] | 13.9 | | 2.82 | bc | 0.16 | ab |
| $GA_{4+7}$ + 6-BA 20[a] | 13.7 | | 2.21 | d | 0.16 | ab |
| *Significance level* | *0.0524* | | ***<0001*** | | ***0.0402*** | |
| *LSD 5%* | - | | *0.25* | | *0.02* | |
| *Untreated control vs. rest* | *0.4947* | | ***0.0032*** | | ***0.0390*** | |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.2032* | | ***<0001*** | | *0.4974* | |
| *$GA_{4+7}$ Linear* | ***0.0089*** | | ***<0001*** | | *0.2600* | |
| *$GA_{4+7}$ Quadratic* | *0.3917* | | *0.9756* | | ***0.0107*** | |
| *$GA_{4+7}$ + 6-BA Linear* | *0.2789* | | ***<0001*** | | *0.2796* | |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.1434* | | ***0.0199*** | | *0.7031* | |

[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 5, 11 and 18 Oct. 2017

Table 5. Pearson correlation coefficients ($R^2$) between pedicel length and apple length, -diameter and -weight of 'Nicoter', 'Fuji' and 'Cripps' Pink' apples in the 2017/2018 and 2018/2019 season.

| | 'Nicoter' | | 'Fuji' | | 'Cripps' Pink' | |
|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2018 | 2019 | 2018 | 2019 |
| | Pedicel length | | | | | |
| Apple length | 0.1666 | 0.3316 | 0.2536 | 0.1938 | -0.0127 | 0.2018 |
| *p*-value | ***<0001*** | ***<0001*** | ***<0001*** | ***<0001*** | *0.4650* | ***<0001*** |
| Apple diameter | 0.1289 | 0.2010 | 0.1144 | 0.1564 | -0.0285 | -0.0315 |
| *p*-value | ***<0001*** | ***<0001*** | ***<0001*** | ***<0001*** | *0.1005* | *0.1164* |
| Apple weight | 0.1475 | 0.2663 | 0.1823 | 0.1688 | -0.0373 | 0.0696 |
| *p*-value | ***<0001*** | ***<0001*** | ***<0001*** | ***<0001*** | ***0.0316*** | ***0.0005*** |
| Pedicel diameter | *-0.0934* | *-0.0212* | *-0.0079* | *0.0277* | *-0.0217* | *-0.0258* |
| *p*-value | ***<0001*** | *0.1538* | *0.6497* | *0.1673* | *0.2124* | *0.2009* |
| Pedicel weight | *0.0953* | *0.0157* | *0.3286* | *0.3488* | *0.1934* | *0.2282* |
| *p*-value | ***<0001*** | *0.2919* | ***<0001*** | ***<0001*** | ***<0001*** | ***<0001*** |

Table 6. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on fruit set per cluster on two marked branches and number of hand thinned fruitlets per tree of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2017/2018).

| Treatment | Average fruit set per cluster on two tagged branches* | | Average number of hand thinned fruitlets per tree | |
|---|---|---|---|---|
| Untreated control | 1.39 | ns | 112.57 | a |
| $GA_{4+7}$ 5[a] | 1.26 | | 78.29 | bc |
| $GA_{4+7}$ 10[a] | 1.52 | | 75.14 | bc |
| $GA_{4+7}$ 20[a] | 1.50 | | 89.71 | abc |
| $GA_{4+7}$ + 6-BA 5[a] | 1.38 | | 100.00 | ab |
| $GA_{4+7}$ + 6-BA 10[a] | 1.71 | | 105.00 | ab |
| $GA_{4+7}$ + 6-BA 20[a] | 1.43 | | 64.86 | c |
| *Significance level* | *0.5771* | | ***0.0306*** | |
| *LSD 5%* | - | | *30.64* | |
| *Untreated control vs. rest* | *0.6623* | | ***0.0246*** | |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.5318* | | *0.3141* | |
| *$GA_{4+7}$ Linear* | *0.3653* | | *0.3896* | |
| *$GA_{4+7}$ Quadratic* | *0.3461* | | *0.6050* | |
| *$GA_{4+7}$ + 6-BA Linear* | *0.9456* | | ***0.0131*** | |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.1267* | | *0.2177* | |

* Number of fruits after natural fruit drop /number of flower clusters at bloom
[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 5, 11 and 18 Oct. 2017

Table 7. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on the fruit size of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2017/2018).

| Treatment | Average fruit weight at 2018 harvest (g) | | Average fruit length at 2018 harvest (mm) | | Average fruit diameter at 2018 harvest (mm) | |
|---|---|---|---|---|---|---|
| Untreated control | 134.9 | ns | 54.2 | ns | 68.6 | ns |
| $GA_{4+7}$ 5[a] | 129.4 | | 55.2 | | 68.6 | |
| $GA_{4+7}$ 10[a] | 131.4 | | 54.8 | | 68.2 | |
| $GA_{4+7}$ 20[a] | 130.8 | | 54.4 | | 68.3 | |
| $GA_{4+7}$ + 6-BA 5[a] | 134.9 | | 54.7 | | 69.5 | |
| $GA_{4+7}$ + 6-BA 10[a] | 135.4 | | 55.1 | | 68.9 | |
| $GA_{4+7}$ + 6-BA 20[a] | 138.2 | | 56.4 | | 69.6 | |
| *Significance level* | *0.3467* | | *0.0991* | | *0.3459* | |
| *LSD 5%* | - | | - | | - | |
| *Untreated control vs. rest* | *0.5654* | | *0.0962* | | *0.7275* | |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | ***0.0226*** | | *0.1579* | | ***0.0253*** | |
| *$GA_{4+7}$ Linear* | *0.8031* | | *0.3266* | | *0.7756* | |
| *$GA_{4+7}$ Quadratic* | *0.6745* | | *0.8424* | | *0.6978* | |
| *$GA_{4+7}$ + 6-BA Linear* | *0.4079* | | ***0.0231*** | | *0.7026* | |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.8629* | | *0.8483* | | *0.3142* | |

[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 5, 11 and 18 Oct. 2017

Table 8. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on the fruit quality of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2017/2018).

| Treatment | % Fruit with calyx-end ribbing | | % Fruit with pedicel-end cracking | |
|---|---|---|---|---|
| Untreated control | 6.00 | d | 13.14 | d |
| $GA_{4+7}$ 5[a] | 56.29 | bc | 50.00 | a |
| $GA_{4+7}$ 10[a] | 63.14 | abc | 31.43 | bc |
| $GA_{4+7}$ 20[a] | 60.29 | bc | 40.29 | ab |
| $GA_{4+7}$ + 6-BA 5[a] | 51.14 | c | 52.00 | a |
| $GA_{4+7}$ + 6-BA 10[a] | 75.14 | a | 20.29 | cd |
| $GA_{4+7}$ + 6-BA 20[a] | 67.71 | ab | 16.86 | d |
| *Significance level* | ***<.0001*** | | ***<.0001*** | |
| *LSD 5%* | *14.67* | | *14.26* | |
| *Untreated control vs. rest* | ***<.0001*** | | ***0.0002*** | |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.2618* | | ***0.0112*** | |
| *$GA_{4+7}$ Linear* | *0.6941* | | *0.3580* | |
| *$GA_{4+7}$ Quadratic* | *0.3924* | | ***0.0183*** | |
| *$GA_{4+7}$ + 6-BA Linear* | *0.0843* | | ***<.0001*** | |
| *$GA_{4+7}$ + 6-BA Quadratic* | ***0.0064*** | | ***0.0027*** | |

[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 5, 11 and 18 Oct. 2017

Table 9. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on the yield efficiency and the return bloom of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2017/2018).

| Treatment | Total yield per tree (kg) | | Estimated yield per hectare (ton) | Total yield Efficiency ($kg \cdot cm^{-2}$) | | Percentage return bloom on two tagged branches* | |
|---|---|---|---|---|---|---|---|
| Untreated control | 30.2 | ns | 60.4 | 0.78 | ns | 59.86 | ns |
| $GA_{4+7}$ 5[a] | 31.4 | | 62.8 | 0.77 | | 60.63 | |
| $GA_{4+7}$ 10[a] | 21.0 | | 42.0 | 0.52 | | 66.50 | |
| $GA_{4+7}$ 20[a] | 34.6 | | 69.2 | 0.76 | | 55.15 | |
| $GA_{4+7}$ + 6-BA 5[a] | 27.4 | | 54.8 | 0.67 | | 66.61 | |
| $GA_{4+7}$ + 6-BA 10[a] | 22.6 | | 45.2 | 0.47 | | 46.22 | |
| $GA_{4+7}$ + 6-BA 20[a] | 25.5 | | 51.0 | 0.60 | | 61.04 | |
| *Significance level* | *0.1335* | | - | *0.0630* | | *0.7570* | |
| *LSD 5%* | - | | - | - | | - | |
| *Untreated control vs. rest* | *0.4338* | | - | *0.1116* | | *0.2600* | |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.2121* | | - | *0.1514* | | *0.4721* | |
| *$GA_{4+7}$ Linear* | *0.2771* | | - | *0.6971* | | *0.7304* | |
| *$GA_{4+7}$ Quadratic* | ***0.0167*** | | - | ***0.0249*** | | *0.6287* | |
| *$GA_{4+7}$ + 6-BA Linear* | *0.8481* | | - | *0.7666* | | *0.3127* | |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.3733* | | - | *0.1023* | | *0.7190* | |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds).

[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 5, 11 and 18 Oct. 2017

Table 10. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on the pedicel size of 'Fuji' apples at Oak Valley, Elgin, South Africa (2017/2018).

| Treatment | Average pedicel length at 2018 harvest (mm) | Average pedicel diameter at 2018 harvest (mm) | Average pedicel weight at 2018 harvest (g) |
|---|---|---|---|
| Untreated control | 15.5 c | 2.30 a | 0.11 b |
| $GA_{4+7}$ 5[a] | 18.6 b | 2.08 c | 0.11 b |
| $GA_{4+7}$ 10[a] | 18.5 b | 1.98 d | 0.10 c |
| $GA_{4+7}$ 20[a] | 19.9 a | 2.05 cd | 0.10 bc |
| $GA_{4+7}$ + 6-BA 5[a] | 18.4 b | 2.21 b | 0.13 a |
| $GA_{4+7}$ + 6-BA 10[a] | 19.3 ab | 2.20 b | 0.14 a |
| $GA_{4+7}$ + 6-BA 20[a] | 19.9 a | 2.32 a | 0.14 a |
| *Significance level* | ***<.0001*** | ***<.0001*** | ***<.0001*** |
| *LSD 5%* | *1.26* | *0.09* | *0.01* |
| *Untreated control vs. rest* | ***<.0001*** | ***<.0001*** | *0.0917* |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.6015* | ***<.0001*** | ***<.0001*** |
| *$GA_{4+7}$ Linear* | ***0.0276*** | *0.7657* | *0.2244* |
| *$GA_{4+7}$ Quadratic* | *0.2871* | ***0.0318*** | ***0.0269*** |
| *$GA_{4+7}$ + 6-BA Linear* | ***0.0210*** | ***0.0116*** | *0.2296* |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.4799* | *0.2499* | *0.7564* |

[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 28 Sep. 2017 + 5 and 11 Oct. 2017

Table 11. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on fruit set per cluster on two marked branches of 'Fuji' apples at Oak Valley, Elgin, South Africa (2017/2018).

| Treatment | Average fruit set per cluster on two tagged branches* |
|---|---|
| Untreated control | 0.69 ns |
| $GA_{4+7}$ 5[a] | 0.72 |
| $GA_{4+7}$ 10[a] | 0.73 |
| $GA_{4+7}$ 20[a] | 0.66 |
| $GA_{4+7}$ + 6-BA 5[a] | 0.68 |
| $GA_{4+7}$ + 6-BA 10[a] | 0.62 |
| $GA_{4+7}$ + 6-BA 20[a] | 0.75 |
| *Significance level* | *0.8294* |
| *LSD 5%* | - |
| *Untreated control vs. rest* | *0.9354* |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.7183* |
| *$GA_{4+7}$ Linear* | *0.5061* |
| *$GA_{4+7}$ Quadratic* | *0.7585* |
| *$GA_{4+7}$ + 6-BA Linear* | *0.3373* |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.2811* |

* Number of fruits after natural fruit drop /number of flower clusters at bloom;
[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 28 Sep. 2017 + 5 and 11 Oct. 2017

Table 12. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on the fruit size of 'Fuji' apples at Oak Valley, Elgin, South Africa (2017/2018).

| Treatment | Average fruit weight at 2018 harvest (g) | Average fruit length at 2018 harvest (mm) | Average fruit diameter at 2018 harvest (mm) |
|---|---|---|---|
| Untreated control | 138.9 ns | 55.9 ns | 70.9 ns |
| $GA_{4+7}$ 5[a] | 130.9 | 54.9 | 68.9 |
| $GA_{4+7}$ 10[a] | 126.4 | 54.1 | 68.3 |
| $GA_{4+7}$ 20[a] | 125.5 | 54.0 | 68.2 |
| $GA_{4+7}$ + 6-BA 5[a] | 127.6 | 54.8 | 68.2 |
| $GA_{4+7}$ + 6-BA 10[a] | 128.2 | 54.7 | 68.8 |
| $GA_{4+7}$ + 6-BA 20[a] | 132.5 | 55.8 | 69.1 |
| *Significance level* | *0.2597* | *0.1847* | *0.1215* |
| *LSD 5%* | - | - | - |
| *Untreated control vs. rest* | ***0.0200*** | *0.0760* | ***0.0039*** |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.5801* | *0.1240* | *0.6587* |
| *$GA_{4+7}$ Linear* | *0.3896* | *0.3461* | *0.5381* |
| *$GA_{4+7}$ Quadratic* | *0.5871* | *0.5265* | *0.7256* |
| *$GA_{4+7}$ + 6-BA Linear* | *0.3656* | *0.1743* | *0.3920* |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.8277* | *0.5949* | *0.7740* |

[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 28 Sep. 2017 + 5 and 11 Oct. 2017

Table 13. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on calyx-end ribbing, yield efficiency and return bloom of 'Fuji' apples at Oak Valley, Elgin, South Africa (2017/2018).

| Treatment | % Fruit with calyx-end ribbing | Total yield per tree (kg) | Estimated yield per hectare (ton) | Total yield Efficiency (kg·cm$^{-2}$) | Percentage return bloom on two tagged branches* |
|---|---|---|---|---|---|
| Untreated control | 25.40 c | 50.0 ns | 100.0 | 0.45 ns | 30.80 ns |
| $GA_{4+7}$ 5[a] | 37.00 bc | 49.5 | 99.00 | 0.49 | 28.73 |
| $GA_{4+7}$ 10[a] | 42.40 b | 56.0 | 112.0 | 0.46 | 24.62 |
| $GA_{4+7}$ 20[a] | 40.20 b | 54.9 | 109.8 | 0.42 | 18.71 |
| $GA_{4+7}$ + 6-BA 5[a] | 63.20 a | 46.4 | 92.80 | 0.49 | 33.28 |
| $GA_{4+7}$ + 6-BA 10[a] | 61.20 a | 48.0 | 96.00 | 0.44 | 23.90 |
| $GA_{4+7}$ + 6-BA 20[a] | 63.60 a | 53.6 | 107.2 | 0.41 | 22.14 |
| *Significance level* | ***<.0001*** | *0.4571* | - | *0.3670* | *0.0695* |
| *LSD 5%* | *12.57* | - | - | - | - |
| *Untreated control vs. rest* | ***<.0001*** | *0.7287* | - | *0.8596* | *0.1520* |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | ***<.0001*** | *0.1796* | - | *0.7050* | *0.4072* |
| *$GA_{4+7}$ Linear* | *0.7136* | *0.4045* | - | *0.0846* | *0.0505* |
| *$GA_{4+7}$ Quadratic* | *0.4366* | *0.3130* | - | *0.9663* | *0.8631* |
| *$GA_{4+7}$ + 6-BA Linear* | *0.8898* | *0.1581* | - | *0.0861* | ***0.0490*** |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.7011* | *0.8558* | - | *0.5529* | *0.2055* |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds).
[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 28 Sep. 2017 + 5 and 11 Oct. 2017

Table 14. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on the pedicel size of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa (2017/2018).

| Treatment | Average pedicel length at 2018 harvest (mm) | | Average pedicel diameter at 2018 harvest (mm) | | Average pedicel weight at 2018 harvest (g) | |
|---|---|---|---|---|---|---|
| Untreated control | 14.2 | b | 1.74 | d | 0.05 | e |
| $GA_{4+7}$ 5[a] | 14.4 | b | 2.04 | bc | 0.07 | d |
| $GA_{4+7}$ 10[a] | 13.2 | bc | 2.34 | a | 0.08 | c |
| $GA_{4+7}$ 20[a] | 13.2 | bc | 2.14 | b | 0.06 | d |
| $GA_{4+7}$ + 6-BA 5[a] | 12.3 | c | 2.14 | b | 0.08 | bc |
| $GA_{4+7}$ + 6-BA 10[a] | 13.2 | bc | 2.03 | bc | 0.09 | b |
| $GA_{4+7}$ + 6-BA 20[a] | 16.6 | a | 1.96 | c | 0.10 | a |
| *Significance level* | ***<.0001*** | | ***<.0001*** | | ***<.0001*** | |
| *LSD 5%* | *1.31* | | *0.14* | | *0.0079* | |
| *Untreated control vs. rest* | *0.4600* | | ***<.0001*** | | ***<.0001*** | |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.2690* | | ***0.0040*** | | ***<.0001*** | |
| *$GA_{4+7}$ Linear* | *0.0974* | | *0.6328* | | *0.0777* | |
| *$GA_{4+7}$ Quadratic* | *0.1747* | | ***0.0002*** | | ***0.0008*** | |
| *$GA_{4+7}$ + 6-BA Linear* | ***<.0001*** | | ***0.0226*** | | ***0.0002*** | |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.3733* | | *0.4949* | | *0.8102* | |

[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 4, 11 and 18 Oct. 2017

Table 15. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on fruit set per cluster on two marked branches and number of hand thinned fruitlets per tree of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa (2017/2018).

| Treatment | Average fruit set per cluster on two tagged branches* | | Average number of hand thinned fruitlets per tree | |
|---|---|---|---|---|
| Untreated control | 0.23 | a | 86.70 | a |
| $GA_{4+7}$ 5[a] | 0.16 | ab | 73.40 | ab |
| $GA_{4+7}$ 10[a] | 0.14 | bc | 93.30 | a |
| $GA_{4+7}$ 20[a] | 0.12 | bc | 94.50 | a |
| $GA_{4+7}$ + 6-BA 5[a] | 0.11 | bc | 94.50 | a |
| $GA_{4+7}$ + 6-BA 10[a] | 0.08 | bc | 93.40 | a |
| $GA_{4+7}$ + 6-BA 20[a] | 0.07 | c | 30.90 | b |
| *Significance level* | ***0.0026*** | | ***0.0448*** | |
| *LSD 5%* | *0.08* | | *43.34* | |
| *Untreated control vs. rest* | ***0.0002*** | | *0.6865* | |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | ***0.0284*** | | *0.2625* | |
| *$GA_{4+7}$ Linear* | *0.3026* | | *0.3914* | |
| *$GA_{4+7}$ Quadratic* | *0.9904* | | *0.5027* | |
| *$GA_{4+7}$ + 6-BA Linear* | *0.3620* | | ***0.0023*** | |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.6339* | | *0.2965* | |

* Number of fruits after natural fruit drop /number of flower clusters at bloom; [a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 4, 11 and 18 Oct. 2017

Table 16. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on the fruit size of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa (2017/2018).

| Treatment | Average fruit weight at 2018 harvest (g) | | Average fruit length at 2018 harvest (mm) | | Average fruit diameter at 2018 harvest (mm) | |
|---|---|---|---|---|---|---|
| Untreated control | 130.3 | ns | 60.0 | ns | 68.2 | cd |
| $GA_{4+7}$ 5[a] | 127.3 | | 59.1 | | 67.5 | d |
| $GA_{4+7}$ 10[a] | 127.6 | | 58.3 | | 68.7 | cd |
| $GA_{4+7}$ 20[a] | 129.7 | | 59.4 | | 68.7 | cd |
| $GA_{4+7}$ + 6-BA 5[a] | 133.8 | | 59.7 | | 69.8 | bc |
| $GA_{4+7}$ + 6-BA 10[a] | 131.3 | | 59.4 | | 72.0 | a |
| $GA_{4+7}$ + 6-BA 20[a] | 129.2 | | 59.5 | | 71.4 | ab |
| *Significance level* | *0.7290* | | *0.3984* | | ***<.0001*** | |
| *LSD 5%* | - | | - | | *1.60* | |
| *Untreated control vs. rest* | *0.8809* | | *0.1990* | | ***0.0182*** | |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.1764* | | *0.1523* | | ***<.0001*** | |
| *$GA_{4+7}$ Linear* | *0.5259* | | *0.4956* | | *0.2277* | |
| *$GA_{4+7}$ Quadratic* | *0.8903* | | *0.1644* | | *0.2662* | |
| *$GA_{4+7}$ + 6-BA Linear* | *0.2781* | | *0.8969* | | *0.1343* | |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.7872* | | *0.7762* | | ***0.0195*** | |

[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 4, 11 and 18 Oct. 2017

Table 17. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) and 6-benzyladenine (6-BA) on calyx-end ribbing, yield efficiency and return bloom of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa (2017/2018).

| Treatment | % Fruit with calyx-end ribbing | | Total yield per tree (kg) | | Estimated yield per hectare (ton) | Total yield Efficiency ($kg \cdot cm^{-2}$) | | Percentage return bloom on two tagged branches* | |
|---|---|---|---|---|---|---|---|---|---|
| Untreated control | 4.00 | ns | 32.3 | a | 61.52 | 0.24 | a | 27.86 | ns |
| $GA_{4+7}$ 5[a] | 6.00 | | 24.5 | a | 46.67 | 0.19 | a | 27.38 | |
| $GA_{4+7}$ 10[a] | 1.80 | | 25.5 | a | 48.57 | 0.19 | a | 29.48 | |
| $GA_{4+7}$ 20[a] | 3.80 | | 28.4 | a | 54.10 | 0.21 | a | 29.65 | |
| $GA_{4+7}$ + 6-BA 5[a] | 5.00 | | 28.1 | a | 53.52 | 0.22 | a | 32.98 | |
| $GA_{4+7}$ + 6-BA 10[a] | 2.60 | | 29.2 | a | 55.62 | 0.22 | a | 28.99 | |
| $GA_{4+7}$ + 6-BA 20[a] | 7.80 | | 12.4 | b | 23.62 | 0.11 | b | 25.22 | |
| *Significance level* | *0.0939* | | ***0.0002*** | | - | ***0.0011*** | | *0.1591* | |
| *LSD 5%* | - | | *7.81* | | - | *0.06* | | - | |
| *Untreated control vs. rest* | *0.7544* | | ***0.0131*** | | - | ***0.0202*** | | *0.5949* | |
| *$GA_{4+7}$ vs. $GA_{4+7}$ + 6-BA* | *0.2967* | | *0.2013* | | - | *0.4067* | | *0.8850* | |
| *$GA_{4+7}$ Linear* | *0.4791* | | *0.3018* | | - | *0.3560* | | *0.4515* | |
| *$GA_{4+7}$ Quadratic* | *0.0644* | | *0.9162* | | - | *0.8635* | | *0.5704* | |
| *$GA_{4+7}$ + 6-BA Linear* | *0.0914* | | ***<.0001*** | | - | ***0.0001*** | | ***0.0061*** | |
| *$GA_{4+7}$ + 6-BA Quadratic* | *0.0750* | | *0.0698* | | - | *0.1771* | | *0.5520* | |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds).
[a] $GA_{4+7}$ and $GA_{4+7}$ + 6-BA applied: 4, 11 and 18 Oct. 2017

Table 18. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the pedicel size of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2018/2019).

| Treatment | Average pedicel length at 2019 harvest (mm) | | Average pedicel diameter at 2019 harvest (mm) | | Average pedicel weight at 2019 harvest (g) | |
|---|---|---|---|---|---|---|
| Untreated control | 15.34 | de | 2.74 | a | 0.17 | a |
| $GA_{4+7}$ 50 (x1) [a] | 15.68 | cde | 2.62 | bc | 0.16 | ab |
| $GA_{4+7}$ 100 (x1) [a] | 16.44 | bcd | 2.64 | ab | 0.18 | a |
| $GA_{4+7}$ 200 (x1) [a] | 16.69 | bc | 2.65 | ab | 0.18 | a |
| $GA_{4+7}$ 50 (x2) [b] | 17.19 | ab | 2.49 | c | 0.14 | bc |
| $GA_{4+7}$ 100 (x2) [b] | 17.95 | a | 2.61 | bc | 0.16 | ab |
| $GA_{4+7}$ 200 (x2) [b] | 18.14 | a | 2.34 | d | 0.13 | cd |
| $GA_{4+7}$ 20 (x2) [b] | 15.26 | de | 2.60 | bc | 0.15 | bc |
| $GA_{4+7}$ 10 (x4) [c] | 15.19 | e | 2.53 | bc | 0.12 | d |
| *Significance level* | ***<.0001*** | | ***<.0001*** | | ***<.0001*** | |
| *LSD 5%* | *1.19* | | *0.12* | | *0.03* | |
| *Untreated control vs. rest* | ***0.0078*** | | ***0.0002*** | | *0.0539* | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | ***<.0001*** | | ***<.0001*** | | ***0.0003*** | |
| *$GA_{4+7}$ (x1) Linear* | *0.1218* | | *0.5889* | | *0.1646* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.4250* | | *0.7838* | | *0.2825* | |
| *$GA_{4+7}$ (x2) Linear* | *0.1475* | | ***0.0019*** | | *0.1189* | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.4029* | | ***0.0025*** | | ***0.0380*** | |

[a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 19 Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on fruit set per cluster on two tagged branches and number of hand thinned fruitlets per tree of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2018/2019).

| Treatment | Average fruit set per cluster on two tagged branches* | | Average number of hand thinned fruitlets per tree | |
|---|---|---|---|---|
| Untreated control | 0.96 | a | 337.90 | a |
| $GA_{4+7}$ 50 (x1) [a] | 0.78 | ab | 252.50 | abc |
| $GA_{4+7}$ 100 (x1) [a] | 0.65 | abcd | 203.70 | bcd |
| $GA_{4+7}$ 200 (x1) [a] | 0.50 | bcd | 99.80 | d |
| $GA_{4+7}$ 50 (x2) [b] | 0.94 | a | 241.10 | abc |
| $GA_{4+7}$ 100 (x2) [b] | 0.41 | cd | 146.70 | cd |
| $GA_{4+7}$ 200 (x2) [b] | 0.34 | d | 111.40 | d |
| $GA_{4+7}$ 20 (x2) [b] | 0.71 | abc | 291.30 | ab |
| $GA_{4+7}$ 10 (x4) [c] | 0.57 | bcd | 198.40 | bcd |
| *Significance level* | ***0.0069*** | | ***0.0006*** | |
| *LSD 5%* | *0.36* | | *113.6* | |
| *Untreated control vs. rest* | ***0.0127*** | | ***0.0011*** | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | *0.4365* | | *0.5668* | |
| *$GA_{4+7}$ (x1) Linear* | *0.1304* | | ***0.0078*** | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.8112* | | *0.9668* | |
| *$GA_{4+7}$ (x2) Linear* | ***0.0041*** | | ***0.0373*** | |
| *$GA_{4+7}$ (x2) Quadratic* | ***0.0406*** | | *0.3120* | |

* Number of fruits after natural fruit drop /number of flower clusters at bloom; [a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 20. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the fruit size of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2018/2019).

| Treatment | Average fruit weight at 2019 harvest (g) | | Average fruit length at 2019 harvest (mm) | | Average fruit diameter at 2019 harvest (mm) | |
|---|---|---|---|---|---|---|
| Untreated control | 109.24 | cd | 51.01 | de | 62.62 | d |
| $GA_{4+7}$ 50 (x1) [a] | 112.55 | bcd | 52.32 | bcde | 63.27 | cd |
| $GA_{4+7}$ 100 (x1) [a] | 112.20 | cd | 52.05 | cde | 63.11 | cd |
| $GA_{4+7}$ 200 (x1) [a] | 123.18 | ab | 54.25 | ab | 65.31 | b |
| $GA_{4+7}$ 50 (x2) [b] | 115.63 | bc | 52.87 | bcd | 64.83 | bc |
| $GA_{4+7}$ 100 (x2) [b] | 117.32 | bc | 53.67 | abc | 65.27 | b |
| $GA_{4+7}$ 200 (x2) [b] | 129.75 | a | 55.49 | a | 67.37 | a |
| $GA_{4+7}$ 20 (x2) [b] | 104.61 | d | 50.57 | e | 63.39 | bcd |
| $GA_{4+7}$ 10 (x4) [c] | 108.76 | cd | 51.04 | de | 64.40 | bcd |
| *Significance level* | ***0.0005*** | | ***<.0001*** | | ***0.0002*** | |
| *LSD 5%* | *10.93* | | *2.11* | | *1.97* | |
| *Untreated control vs. rest* | *0.1318* | | ***0.0285*** | | ***0.0088*** | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | *0.1239* | | *0.0671* | | ***0.0012*** | |
| *$GA_{4+7}$ (x1) Linear* | ***0.0366*** | | ***0.0450*** | | ***0.0257*** | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.4226* | | *0.3311* | | *0.3369* | |
| *$GA_{4+7}$ (x2) Linear* | ***0.0076*** | | ***0.0132*** | | ***0.0086*** | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.5351* | | *0.9368* | | *0.6427* | |

[a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 21. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on fruit drop during harvest and calyx-end ribbing of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2018/2019).

| Treatment | % Fruit with calyx-end ribbing | | Average number of fruit that dropped during harvest | |
|---|---|---|---|---|
| Untreated control | 4.33 | f | 3.7 | ns |
| $GA_{4+7}$ 50 (x1) [a] | 10.50 | def | 2.5 | |
| $GA_{4+7}$ 100 (x1) [a] | 14.17 | cde | 5.0 | |
| $GA_{4+7}$ 200 (x1) [a] | 27.67 | ab | 3.1 | |
| $GA_{4+7}$ 50 (x2) [b] | 19.33 | bcd | 4.4 | |
| $GA_{4+7}$ 100 (x2) [b] | 22.17 | bc | 2.7 | |
| $GA_{4+7}$ 200 (x2) [b] | 33.67 | a | 2.3 | |
| $GA_{4+7}$ 20 (x2) [b] | 10.17 | def | 4.7 | |
| $GA_{4+7}$ 10 (x4) [c] | 5.67 | ef | 5.0 | |
| *Significance level* | ***<.0001*** | | *0.1560* | |
| *LSD 5%* | *9.24* | | - | |
| *Untreated control vs. rest* | ***0.0002*** | | *0.9894* | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | ***0.0058*** | | *0.5802* | |
| *$GA_{4+7}$ (x1) Linear* | ***0.0002*** | | *0.9305* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.6166* | | ***0.0400*** | |
| *$GA_{4+7}$ (x2) Linear* | ***0.0018*** | | *0.1279* | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.6357* | | *0.3662* | |

[a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 22. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the yield efficiency and return bloom of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2018/2019).

| Treatment | Total yield per tree (kg) | | Estimated yield per hectare (ton) | Total yield efficiency ($kg \cdot cm^{-2}$) | | Percentage return bloom on two tagged branches* | |
|---|---|---|---|---|---|---|---|
| Untreated control | 52.02 | a | 104.04 | 1.39 | ns | 25.38 | ns |
| $GA_{4+7}$ 50 (x1) [a] | 55.40 | a | 110.80 | 1.32 | | 31.80 | |
| $GA_{4+7}$ 100 (x1) [a] | 54.04 | a | 108.08 | 1.22 | | 32.76 | |
| $GA_{4+7}$ 200 (x1) [a] | 36.71 | c | 73.42 | 1.00 | | 43.33 | |
| $GA_{4+7}$ 50 (x2) [b] | 50.81 | ab | 101.62 | 1.51 | | 29.66 | |
| $GA_{4+7}$ 100 (x2) [b] | 40.46 | bc | 80.92 | 0.98 | | 27.58 | |
| $GA_{4+7}$ 200 (x2) [b] | 34.46 | c | 68.92 | 0.96 | | 34.29 | |
| $GA_{4+7}$ 20 (x2) [b] | 55.91 | a | 111.82 | 1.37 | | 33.93 | |
| $GA_{4+7}$ 10 (x4) [c] | 52.16 | a | 104.32 | 1.52 | | 23.95 | |
| *Significance level* | ***0.0003*** | | - | *0.0799* | | *0.2536* | |
| *LSD 5%* | *11.47* | | - | - | | - | |
| *Untreated control vs. rest* | *0.2973* | | - | *0.3823* | | *0.2107* | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | ***0.0440*** | | - | *0.8288* | | *0.1913* | |
| *$GA_{4+7}$ (x1) Linear* | ***0.0008*** | | - | *0.1548* | | *0.0884* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.3397* | | - | *0.9736* | | *0.6503* | |
| *$GA_{4+7}$ (x2) Linear* | ***0.0084*** | | - | ***0.0403*** | | *0.4442* | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.3377* | | - | *0.1013* | | *0.5680* | |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds); [a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 23. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the pedicel size of 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

| Treatment | Average pedicel length at 2019 harvest (mm) | | Average pedicel diameter at 2019 harvest (mm) | | Average pedicel weight at 2019 harvest (g) | |
|---|---|---|---|---|---|---|
| Untreated control | 12.80 | bc | 2.41 | ns | 0.08 | ef |
| $GA_{4+7}$ 50 (x1) [a] | 11.50 | c | 2.39 | | 0.08 | f |
| $GA_{4+7}$ 100 (x1) [a] | 13.80 | b | 2.46 | | 0.11 | bcd |
| $GA_{4+7}$ 200 (x1) [a] | 16.09 | a | 2.45 | | 0.14 | a |
| $GA_{4+7}$ 50 (x2) [b] | 14.09 | b | 2.37 | | 0.11 | cd |
| $GA_{4+7}$ 100 (x2) [b] | 14.10 | b | 2.40 | | 0.10 | de |
| $GA_{4+7}$ 200 (x2) [b] | 17.39 | a | 2.54 | | 0.12 | abc |
| $GA_{4+7}$ 20 (x2) [b] | 13.67 | b | 2.33 | | 0.11 | cd |
| $GA_{4+7}$ 10 (x4) [c] | 17.44 | a | 2.47 | | 0.13 | ab |
| *Significance level* | ***<.0001*** | | *0.0984* | | ***<.0001*** | |
| *LSD 5%* | *1.61* | | - | | *0.02* | |
| *Untreated control vs. rest* | ***0.0032*** | | *0.7158* | | ***<.0001*** | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | ***0.0039*** | | *0.9688* | | *0.9745* | |
| *$GA_{4+7}$ (x1) Linear* | ***<.0001*** | | *0.4979* | | ***<.0001*** | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.3078* | | *0.3914* | | *0.1280* | |
| *$GA_{4+7}$ (x2) Linear* | ***<.0001*** | | ***0.0093*** | | ***0.0488*** | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.1300* | | *0.6549* | | *0.1664* | |

[a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 24. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on fruit set per cluster on two tagged branches and number of hand thinned fruitlets per tree of 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

| Treatment | Average fruit set per cluster on two tagged branches* | | Average number of hand thinned fruitlets per tree | |
|---|---|---|---|---|
| Untreated control | 2.05 | ns | 471.4 | ns |
| $GA_{4+7}$ 50 (x1) [a] | 1.93 | | 349.0 | |
| $GA_{4+7}$ 100 (x1) [a] | 2.10 | | 346.9 | |
| $GA_{4+7}$ 200 (x1) [a] | 2.13 | | 342.4 | |
| $GA_{4+7}$ 50 (x2) [b] | 2.83 | | 471.2 | |
| $GA_{4+7}$ 100 (x2) [b] | 1.39 | | 425.2 | |
| $GA_{4+7}$ 200 (x2) [b] | 1.54 | | 357.2 | |
| $GA_{4+7}$ 20 (x2) [b] | 2.68 | | 551.2 | |
| $GA_{4+7}$ 10 (x4) [c] | 1.96 | | 427.8 | |
| *Significance level* | *0.5143* | | *0.0983* | |
| *LSD 5%* | - | | - | |
| *Untreated control vs. rest* | *0.9609* | | *0.2876* | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | *0.7373* | | *0.1146* | |
| *$GA_{4+7}$ (x1) Linear* | *0.7912* | | *0.9312* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.8655* | | *0.9988* | |
| *$GA_{4+7}$ (x2) Linear* | *0.1170* | | *0.1461* | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.1011* | | *0.9075* | |

* Number of fruits after natural fruit drop /number of flower clusters at bloom; [a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 25. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the fruit size of 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

| Treatment | Average fruit weight at 2019 harvest (g) | | Average fruit length at 2019 harvest (mm) | | Average fruit diameter at 2019 harvest (mm) | |
|---|---|---|---|---|---|---|
| Untreated control | 111.60 | bcd | 51.22 | ns | 64.43 | bcd |
| $GA_{4+7}$ 50 (x1) [a] | 112.83 | bcd | 51.07 | | 64.42 | bcd |
| $GA_{4+7}$ 100 (x1) [a] | 115.82 | bc | 51.54 | | 65.18 | abc |
| $GA_{4+7}$ 200 (x1) [a] | 119.37 | ab | 52.34 | | 65.69 | ab |
| $GA_{4+7}$ 50 (x2) [b] | 107.55 | cd | 50.66 | | 63.47 | cd |
| $GA_{4+7}$ 100 (x2) [b] | 105.05 | d | 50.39 | | 62.95 | d |
| $GA_{4+7}$ 200 (x2) [b] | 108.43 | cd | 50.56 | | 63.96 | bcd |
| $GA_{4+7}$ 20 (x2) [b] | 125.54 | a | 52.83 | | 66.95 | a |
| $GA_{4+7}$ 10 (x4) [c] | 113.23 | bcd | 51.52 | | 64.77 | bc |
| *Significance level* | ***0.0012*** | | ***0.0510*** | | ***0.0014*** | |
| *LSD 5%* | *9.30* | | - | | *1.78* | |
| *Untreated control vs. rest* | *0.5927* | | *0.8126* | | *0.7147* | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | ***0.0013*** | | ***0.0191*** | | ***0.0022*** | |
| *$GA_{4+7}$ (x1) Linear* | *0.1683* | | *0.1146* | | *0.1781* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.8446* | | *0.9471* | | *0.6682* | |
| *$GA_{4+7}$ (x2) Linear* | *0.7477* | | *0.9456* | | *0.4744* | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.4992* | | *0.7344* | | *0.3877* | |

[a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 26. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the fruit drop during harvest and calyx-end ribbing of 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

| Treatment | % Fruit with calyx-end ribbing | | Average number of fruit that dropped during harvest | |
|---|---|---|---|---|
| Untreated control | 3.67 | c | 14.6 | ns |
| $GA_{4+7}$ 50 (x1) [a] | 8.67 | bc | 5.3 | |
| $GA_{4+7}$ 100 (x1) [a] | 13.33 | ab | 8.7 | |
| $GA_{4+7}$ 200 (x1) [a] | 20.00 | a | 8.9 | |
| $GA_{4+7}$ 50 (x2) [b] | 17.67 | a | 11.8 | |
| $GA_{4+7}$ 100 (x2) [b] | 15.67 | ab | 10.9 | |
| $GA_{4+7}$ 200 (x2) [b] | 14.67 | ab | 13.2 | |
| $GA_{4+7}$ 20 (x2) [b] | 2.67 | c | 7.9 | |
| $GA_{4+7}$ 10 (x4) [c] | 14.00 | ab | 9.4 | |
| *Significance level* | ***0.0006*** | | *0.0505* | |
| *LSD 5%* | *8.50* | | - | |
| *Untreated control vs. rest* | ***0.0035*** | | ***0.0183*** | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | *0.4191* | | ***0.0093*** | |
| *$GA_{4+7}$ (x1) Linear* | ***0.0096*** | | *0.2604* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.8138* | | *0.3774* | |
| *$GA_{4+7}$ (x2) Linear* | *0.5079* | | *0.5413* | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.7910* | | *0.5828* | |

[a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 27. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the yield efficiency and return bloom of 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

| Treatment | Total yield per tree (kg) | | Estimated yield per hectare (ton) | Total yield efficiency ($kg \cdot cm^{-2}$) | | Percentage return bloom on two tagged branches* | |
|---|---|---|---|---|---|---|---|
| Untreated control | 51.60 | ns | 103.20 | 0.37 | ns | 14.75 | ns |
| $GA_{4+7}$ 50 (x1) [a] | 42.75 | | 85.50 | 0.44 | | 14.37 | |
| $GA_{4+7}$ 100 (x1) [a] | 37.32 | | 74.64 | 0.36 | | 13.04 | |
| $GA_{4+7}$ 200 (x1) [a] | 46.12 | | 92.24 | 0.42 | | 11.89 | |
| $GA_{4+7}$ 50 (x2) [b] | 44.27 | | 88.54 | 0.37 | | 18.25 | |
| $GA_{4+7}$ 100 (x2) [b] | 41.60 | | 83.20 | 0.33 | | 14.59 | |
| $GA_{4+7}$ 200 (x2) [b] | 36.47 | | 72.94 | 0.32 | | 9.76 | |
| $GA_{4+7}$ 20 (x2) [b] | 45.34 | | 90.68 | 0.33 | | 17.39 | |
| $GA_{4+7}$ 10 (x4) [c] | 42.41 | | 84.82 | 0.30 | | 15.26 | |
| *Significance level* | *0.6983* | | - | *0.4064* | | *0.3978* | |
| *LSD 5%* | - | | - | - | | - | |
| *Untreated control vs. rest* | *0.1062* | | - | *0.7376* | | *0.8735* | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | *0.7764* | | - | *0.0740* | | *0.5950* | |
| *$GA_{4+7}$ (x1) Linear* | *0.5347* | | - | *0.9354* | | *0.5005* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.3435* | | - | *0.2129* | | *0.8748* | |
| *$GA_{4+7}$ (x2) Linear* | *0.3131* | | - | *0.5413* | | ***0.0206*** | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.9918* | | - | *0.7170* | | *0.7936* | |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds); [a] $GA_{4+7}$ applied once (x1) at 8 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 8 and 11 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 8, 11, 16 and 19 Oct. 2018

Table 28. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the pedicel size of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa (2018/2019).

| Treatment | Average pedicel length at 2019 harvest (mm) | Average pedicel diameter at 2019 harvest (mm) | Average pedicel weight at 2019 harvest (g) |
|---|---|---|---|
| Untreated control | 15.48 f | 2.54 a | 0.12 cd |
| $GA_{4+7}$ 50 (x1) [a] | 15.93 ef | 2.48 a | 0.10 e |
| $GA_{4+7}$ 100 (x1) [a] | 16.75 e | 2.44 a | 0.10 e |
| $GA_{4+7}$ 200 (x1) [a] | 19.68 d | 2.22 b | 0.11 de |
| $GA_{4+7}$ 50 (x2) [b] | 21.01 c | 2.19 b | 0.13 bc |
| $GA_{4+7}$ 100 (x2) [b] | 22.26 b | 2.21 b | 0.16 a |
| $GA_{4+7}$ 200 (x2) [b] | 23.79 a | 2.06 b | 0.16 a |
| $GA_{4+7}$ 20 (x2) [b] | 19.82 cd | 2.12 b | 0.14 b |
| $GA_{4+7}$ 10 (x4) [c] | 20.15 cd | 2.14 b | 0.13 bc |
| *Significance level* | ***<.0001*** | ***<.0001*** | ***<.0001*** |
| *LSD 5%* | *1.19* | *0.20* | *0.02* |
| *Untreated control vs. rest* | ***<.0001*** | ***<.0001*** | *0.1776* |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | ***<.0001*** | ***0.0002*** | ***<.0001*** |
| *$GA_{4+7}$ (x1) Linear* | ***<.0001*** | ***0.0059*** | *0.1338* |
| *$GA_{4+7}$ (x1) Quadratic* | *0.4208* | *0.5786* | *0.2402* |
| *$GA_{4+7}$ (x2) Linear* | ***<.0001*** | *0.1472* | ***0.0051*** |
| *$GA_{4+7}$ (x2) Quadratic* | *0.5400* | *0.4976* | ***0.0118*** |

[a] $GA_{4+7}$ applied once (x1) at 11 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 11 and 16 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 11, 16, 19 and 22 Oct. 2018

Table 29. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on fruit set per cluster on two tagged branches and number of hand thinned fruitlets per tree of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa (2018/2019).

| Treatment | Average fruit set per cluster on two tagged branches* | Average number of hand thinned fruitlets per tree |
|---|---|---|
| Untreated control | 0.62 a | 118.3 ab |
| $GA_{4+7}$ 50 (x1) [a] | 0.55 ab | 116.9 ab |
| $GA_{4+7}$ 100 (x1) [a] | 0.37 c | 92.0 b |
| $GA_{4+7}$ 200 (x1) [a] | 0.39 c | 115.2 ab |
| $GA_{4+7}$ 50 (x2) [b] | 0.39 c | 94.7 b |
| $GA_{4+7}$ 100 (x2) [b] | 0.32 cd | 90.5 b |
| $GA_{4+7}$ 200 (x2) [b] | 0.17 d | 48.8 c |
| $GA_{4+7}$ 20 (x2) [b] | 0.43 bc | 133.0 a |
| $GA_{4+7}$ 10 (x4) [c] | 0.45 bc | 110.9 ab |
| *Significance level* | ***<.0001*** | ***0.0005*** |
| *LSD 5%* | *0.16* | *34.44* |
| *Untreated control vs. rest* | ***0.0001*** | *0.1679* |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | ***0.0027*** | ***0.0036*** |
| *$GA_{4+7}$ (x1) Linear* | *0.0909* | *0.8365* |
| *$GA_{4+7}$ (x1) Quadratic* | *0.0716* | *0.1146* |
| *$GA_{4+7}$ (x2) Linear* | ***0.0064*** | ***0.0058*** |
| *$GA_{4+7}$ (x2) Quadratic* | *0.9776* | *0.4686* |

* Number of fruits after natural fruit drop /number of flower clusters at bloom; [a] $GA_{4+7}$ applied once (x1) at 11 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 11 and 16 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 11, 16, 19 and 22 Oct. 2018

Table 30. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the fruit size of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa (2018/2019).

| Treatment | Average fruit weight at 2019 harvest (g) | | Average fruit length at 2019 harvest (mm) | | Average fruit diameter at 2019 harvest (mm) | |
|---|---|---|---|---|---|---|
| Untreated control | 106.00 | ns | 54.90 | e | 62.63 | ns |
| $GA_{4+7}$ 50 (x1) [a] | 110.21 | | 55.91 | cde | 63.19 | |
| $GA_{4+7}$ 100 (x1) [a] | 112.98 | | 56.47 | bcd | 63.55 | |
| $GA_{4+7}$ 200 (x1) [a] | 109.40 | | 55.86 | cde | 62.84 | |
| $GA_{4+7}$ 50 (x2) [b] | 113.63 | | 56.72 | bc | 63.28 | |
| $GA_{4+7}$ 100 (x2) [b] | 115.54 | | 57.74 | ab | 63.18 | |
| $GA_{4+7}$ 200 (x2) [b] | 113.12 | | 58.26 | a | 62.67 | |
| $GA_{4+7}$ 20 (x2) [b] | 106.95 | | 55.24 | de | 62.68 | |
| $GA_{4+7}$ 10 (x4) [c] | 111.72 | | 56.40 | cd | 63.65 | |
| *Significance level* | *0.1616* | | ***<.0001*** | | *0.7634* | |
| *LSD 5%* | - | | *1.30* | | - | |
| *Untreated control vs. rest* | ***0.0402*** | | ***0.0010*** | | *0.3405* | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | *0.1283* | | ***0.0002*** | | *0.7085* | |
| *$GA_{4+7}$ (x1) Linear* | *0.6838* | | *0.7843* | | *0.5168* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.3459* | | *0.3212* | | *0.4422* | |
| *$GA_{4+7}$ (x2) Linear* | *0.7913* | | ***0.0282*** | | *0.3595* | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.5191* | | *0.3820* | | *0.8754* | |

[a] $GA_{4+7}$ applied once (x1) at 11 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 11 and 16 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 11, 16, 19 and 22 Oct. 2018

Table 31. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the fruit drop during harvest and calyx-end ribbing of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa (2018/2019).

| Treatment | % Fruit with calyx-end ribbing | | Average number of fruit that dropped during harvest | |
|---|---|---|---|---|
| Untreated control | 0.00 | ns | 2.5 | ns |
| $GA_{4+7}$ 50 (x1) [a] | 0.33 | | 1.1 | |
| $GA_{4+7}$ 100 (x1) [a] | 0.33 | | 1.1 | |
| $GA_{4+7}$ 200 (x1) [a] | 0.00 | | 1.9 | |
| $GA_{4+7}$ 50 (x2) [b] | 0.67 | | 2.0 | |
| $GA_{4+7}$ 100 (x2) [b] | 0.33 | | 1.9 | |
| $GA_{4+7}$ 200 (x2) [b] | 1.00 | | 1.6 | |
| $GA_{4+7}$ 20 (x2) [b] | 0.33 | | 1.7 | |
| $GA_{4+7}$ 10 (x4) [c] | 0.33 | | 1.6 | |
| *Significance level* | *0.6050* | | *0.6208* | |
| *LSD 5%* | - | | - | |
| *Untreated control vs. rest* | *0.2599* | | *0.0972* | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | *0.1200* | | *0.2548* | |
| *$GA_{4+7}$ (x1) Linear* | *0.4597* | | *0.2192* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.7975* | | *0.6689* | |
| *$GA_{4+7}$ (x2) Linear* | *0.3753* | | *0.5578* | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.3064* | | *0.9573* | |

[a] $GA_{4+7}$ applied once (x1) at 11 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 11 and 16 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 11, 16, 19 and 22 Oct. 2018

Table 32. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the yield efficiency and return bloom of 'Cripps' Pink' apples at Applegarth, Elgin, South Africa (2018/2019).

| Treatment | Total yield per tree (kg) | | Estimated yield per hectare (ton) | Total yield efficiency ($kg \cdot cm^{-2}$) | | Percentage return bloom on two tagged branches* | |
|---|---|---|---|---|---|---|---|
| Untreated control | 58.05 | a | 96.75 | 0.58 | a | 31.40 | ab |
| $GA_{4+7}$ 50 (x1) [a] | 53.82 | a | 89.70 | 0.53 | ab | 25.36 | bc |
| $GA_{4+7}$ 100 (x1) [a] | 49.41 | ab | 82.35 | 0.48 | ab | 26.96 | abc |
| $GA_{4+7}$ 200 (x1) [a] | 50.03 | ab | 83.38 | 0.46 | bc | 26.79 | abc |
| $GA_{4+7}$ 50 (x2) [b] | 40.32 | bc | 67.20 | 0.36 | c | 28.86 | ab |
| $GA_{4+7}$ 100 (x2) [b] | 36.79 | cd | 61.32 | 0.36 | c | 27.46 | abc |
| $GA_{4+7}$ 200 (x2) [b] | 25.89 | d | 43.15 | 0.24 | d | 21.40 | c |
| $GA_{4+7}$ 20 (x2) [b] | 54.75 | a | 91.25 | 0.53 | ab | 32.92 | a |
| $GA_{4+7}$ 10 (x4) [c] | 50.69 | ab | 84.48 | 0.49 | ab | 27.86 | abc |
| *Significance level* | ***<.0001*** | | - | ***<.0001*** | | ***0.0498*** | |
| *LSD 5%* | *11.72* | | - | *0.11* | | *0.07* | |
| *Untreated control vs. rest* | ***0.0048*** | | - | ***0.0004*** | | *0.0941* | |
| $GA_{4+7}$ (x1) vs. $GA_{4+7}$ (x2) | ***<.0001*** | | - | ***<.0001*** | | *0.7642* | |
| *$GA_{4+7}$ (x1) Linear* | *0.5914* | | - | *0.2179* | | *0.6344* | |
| *$GA_{4+7}$ (x1) Quadratic* | *0.5458* | | - | *0.5293* | | *0.7251* | |
| *$GA_{4+7}$ (x2) Linear* | ***0.0131*** | | - | ***0.0147*** | | ***0.0191*** | |
| *$GA_{4+7}$ (x2) Quadratic* | *0.8060* | | - | *0.3429* | | *0.7068* | |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds); [a] $GA_{4+7}$ applied once (x1) at 11 Oct. 2018; [b] $GA_{4+7}$ applied twice (x2) at 11 and 16 Oct. 2018; [c] $GA_{4+7}$ applied four times (x4) at 11, 16, 19 and 22 Oct. 2018

# PAPER 2: Effect of the Flower Position in the Inflorescence and Bearing Shoot Type on Pedicel Development of 'Nicoter', 'Fuji' and 'Cripps' Pink' Apples.

*Additional index words.* Fruit quality, fruit size, flower quality.

***Abstract.***

**The pedicels of 'Fuji', 'Nicoter' and 'Cripps' Pink' apples in the Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) region of South Africa tend to be short, stubby and rigid, but still vary in size within trees. To what extent the variation in pedicel sizes is due to bearing positions within the tree and inflorescence is unclear. The purpose of this study was to evaluate the effect of three bearing shoot types (terminal on spur, short shoot and long shoot) on the inflorescence composition as well as the effect of the three bearing shoot types and two flower positions (K and L in the inflorescence) on pedicel dimensions and flower and subsequent fruit quality. Flower position had little or no effect on the flower characteristics in all three cultivars. The average pedicel length, diameter, fresh weight and receptacle diameter of 'Nicoter', 'Fuji' and 'Cripps' Pink' did not differ between lateral and king flowers. Long shoots had the longest and spurs the shortest average flower pedicel length in 'Nicoter' and 'Cripps' Pink', and in 'Fuji', the flower pedicel length was not affected by the bearing shoot type, but pedicel diameter was significantly thinner on long shoots compared to short shoots and spurs. The average leaf area per cluster of 'Nicoter' and 'Fuji' as well as the flower and leaf number per cluster in 'Fuji' progressively increased from spurs to short and long shoots. In 'Nicoter', the king fruit on long shoots had longer and heavier pedicels than the lateral fruit. While fruit size of 'Nicoter' and 'Cripps' Pink' was not affected by the flower position, the king fruit of 'Fuji' were significantly longer and had a greater diameter than the lateral fruit when borne on short shoots. In 'Cripps' Pink', both the average pedicel length and weight of the fruit were higher on long and short shoots than on spurs, while short shoots had smaller fruit compared to spurs.**

South African apple production is an important industry, with 197 689 tons sold locally and 393 344 tons exported during the 2018 season (Hortgro, 2018). Maintaining top quality fruit is vital to ensure continued growth in the market. Fruit quality is determined by factors like the soil condition, climatic environment, cultivation practices and tree characteristics (Tomala, 1997). These tree characteristics include the position of the flower in the inflorescence (lateral vs. terminal) that will develop into an apple and the type of shoot that bears the inflorescence (spur, short or long shoot) and subsequent fruit (Tomala, 1997). The effect of the different flower positions on fruit quality has been investigated in several fruit types such as apples (Ferree et al., 2001; Miranda et al., 2005), eggplants (Nothmann and Rylski, 1983), and pomegranates (Wetzstein et al., 2013). An apple flower cluster (botanically cyme) consist of a king (K) flower, that initiates first, and four to five lateral (L) flowers, that initiate in basipetal sequence (Dennis, 1986; Koutinas et al., 2010). The early development of K flowers together with their greater sink potential (Miranda et al., 2005), leads to larger fruit compared to the L flowers in ‘Red Delicious’, ‘Jonagold’ and ‘Golden Delicious’ apples (Ferree et al., 2000; Westwood et al., 1967). This phenomenon was, however, less pronounced in ‘McIntosh’, ‘Gala’ and ‘Empire’ apples (Dennis, 1986; Ferree et al., 2000). Pedicel length also varies between K and L flowers in a cluster. Prive et al. (1988) reported that the L flowers have longer pedicels in ‘McIntosh’, ‘Spartan’, ‘Idared’ and ‘Delicious’ apples compared to the K flowers.

Apple inflorescences develop in the terminal position on spurs and short shoots and in axillary or terminal positions on long shoots (Tromp et al., 1976). The bearing positions alter developmental processes, i.e. long shoots produced the highest budbreak percentage, fruit set, number of flowers per cluster and ratio of leaf area to number of leaves per cluster in ‘Gala’, ‘Daiane’ and ‘Fuji’ and led to a higher length to diameter ratio in ‘Daiane’ apples compared to short shoots and spurs (Rafael et al., 2012). Petri and Leite (2004) found that spur inflorescences develop smaller leaves and subsequently smaller fruit.

The pedicels of ‘Fuji’, ‘Nicoter’ and ‘Cripps’ Pink’ apples in the Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) region of South Africa tend to be short, stubby and rigid and cause losses both pre- and post-harvest (Paper 1; S. Reynolds and J. Moelich, personal communication). Pedicel dimensions, however, vary within trees (Paper 1) and to what extent this is due to bearing position within the tree and inflorescence is unclear. The aim of this study was to evaluate the effect of three bearing shoot types (terminal on spur, short shoot and long shoot) on the inflorescence composition as well as the effect of the three bearing shoot types and two flower positions (K and L in the inflorescence) on pedicel dimensions and flower and subsequent fruit quality.

## Materials and Methods

*Plant material and site description*. The same sites were used as in Paper 1 (2018/2019 season).

*Experimental layout and treatments.* In 2018/2019, the effect of bearing shoot type and flower position on flower pedicel dimensions and inflorescence and fruit quality were evaluated on 'Nicoter', 'Fuji' and 'Cripps' Pink'. A factorial design was used for flower dimensions and fruit quality with position in the cluster (K vs. L) as one factor and type of bearing shoot the second factor. Shoot types were spurs, short shoots (3-30 cm) and long shoots (>30 cm).

*Data collection.* During full bloom, 70 flower clusters of each shoot type were tagged with color-coded cable ties on randomly selected trees. Shoots were chosen that were pointing up- and side-wards. In addition, 25 flower clusters from each shoot type were picked and taken to the laboratory at Stellenbosch University where the following were determined: the number of flowers per cluster, number of leaves per cluster and average leaf area ($cm^2$), the K and average L flower fresh weight (including the pedicel), K and average L flower receptacle diameter, K and average L flower pedicel length and diameter. During the commercial hand thinning period, tagged fruitlet clusters were thinned by hand to either the single K or largest L fruitlet. The remainder of each tree was thinned according to the commercial standard practice for the orchard. At commercial harvest, a sample of 50 fruit per position was harvested and taken to the laboratory where the following were determined: fruit and pedicel length, -weight and -diameter and number of well-developed seeds. Pedicel length was measured from the point of entry into the fruit to the abscission zone and diameter was taken just below the swollen area of the abscission zone. A GÜSS texture analyzer (Guss electronic model GS 20, Strand, South Africa) was used for all apple weight and -diameter recordings. All length measurements and the diameter of the flower receptacle and pedicel were done with an electronic micrometre calliper (Mitutoyo 500, Illinois, USA) and flower and pedicel weight were measured with an electronic precision balance (Kern EWJ, Stuttgart, Germany). A portable leaf area meter (LI-3000C, Nebraska, USA) was used to determine the average leaf area.

*Statistical analysis.* The data were analyzed using SAS Enterprise guide 7.1 (SAS Institute Inc., Cary, North Carolina, USA) using the linear model procedure and the pairwise t-test to determine the Least Significant Difference (LSD) when the F-statistic indicated significance at $P<0.05$.

## Results

*'Nicoter'.* The average flower fresh weight, receptacle diameter, pedicel length and -diameter did not differ between the K and L flowers in a cluster (Table 1). The range of pedicel lengths for K flowers was 9.7 to 29.5 and for lateral flowers slightly wider from 9.5 to 30.6 mm (Table 1). Flowers on long shoots had a significantly lower fresh weight compared to the short shoots and spurs, which had similar fresh weight, and the diameter of the flower receptacles differed significantly among the bearing shoot types, with long shoots having the broadest and short shoots having the thinnest receptacles while spurs were in-between (Table 1). The shortest flower pedicels were found in inflorescences on spurs followed by short shoots with the longest pedicels in inflorescences on long shoots. The length of pedicels ranged from 9.5 to 30.3, 10.2 to 29.1 and 10.8 to 30.6 mm for spurs, short shoots and long shoots, respectively (Table 1). Flower and leaf number per cluster were not affected by the different bearing shoot types, but the average leaf area per cluster differed significantly being the highest on long shoots, followed by short shoots and lowest on spurs (Table 2).

At commercial harvest, the flower position and bearing shoot type had no effect on the average fruit size (weight, length and diameter) (Table 3). The average fruit pedicel diameter was not affected by flower position, but thicker fruit pedicels were found on spurs than on long shoots, while fruit on short shoots did not differ from the latter two (Table 3). The range of pedicel lengths for K fruit was 5.7 to 29.7 and for lateral fruit slightly less from 5.6 to 27.9 mm (Table 3). On the bearing shoot types, the length of pedicels ranged from 5.7 to 27.8, 5.6 to 27.9 and 9.0 to 29.7 mm for spurs, short shoots and long shoots, respectively (Table 3). The fruit pedicel weight and length showed a significant interaction between bearing shoot type and flower position (Table 4). In the case of pedicel length, K fruit had longer and heavier pedicels on long shoots than the L fruit. On spurs, the L fruit had heavier pedicels than the K fruit (Table 4). The number of well-developed seeds were significantly more in K fruit compared to L fruit, while no differences occurred between bearing shoot types (Table 3).

*'Fuji'*. The average flower fresh weight, receptacle diameter, pedicel length and -diameter did not differ between the flower positions (Table 5). The range of pedicel lengths for K flowers was 9.5 to 29.2 and for lateral flowers from 9.3 to 29.8 mm (Table 5). Flowers on long shoots had a significantly lower fresh weight, receptacle diameter and pedicel diameter compared to the short shoots and spurs while the latter two positions did not differ from each other. The average flower pedicel lengths did not differ between bearing shoot types. The length of pedicels ranged from 9.3 to 28.6, 11.7 to 29.6 and 9.8 to 29.8 mm for spurs, short shoots and long shoots, respectively (Table 5). Flower and leaf number and the average leaf area per cluster was the lowest on spurs, followed by short shoots and the highest on long shoots (Table 6).

At commercial harvest, none of the bearing shoot types or flower positions resulted in significant differences in the average fruit weight, number of well-developed seeds, fruit pedicel length and diameter (Table 7). The average fruit pedicel weight did not differ on the bearing shoot types, but K fruit did have significantly heavier pedicels than L fruit. The range of pedicel lengths for K fruit was 2.0 to 22.6 and for lateral fruit slightly narrower from 4.4 to 21.7 mm (Table 7). On the bearing shoot types, the length of pedicels ranged from 2.0 to 17.8, 4.4 to 22.6 and 4.6 to 21.7 mm for spurs, short shoots and long shoots, respectively (Table 7). Significant interaction between bearing shoot type and flower position occurred on the average fruit length and diameter (Table 8). The average fruit length and diameter on spurs and long shoots did not differ between the flower positions, but on short shoots, it was higher for the K fruit (Table 8).

*'Cripps' Pink'*. The average flower fresh weight, receptacle diameter, pedicel length and -diameter did not differ between the flower positions (Table 9). The range of flower pedicel lengths were 10.6 to 30.4 in K flowers while in lateral flowers the range was wider from 7.2 to 33.2 mm. Flowers on long shoots had a significantly higher fresh weight and average pedicel length and a lower receptacle diameter compared to the spurs, but did not differ from the short shoots (Table

9). The length of pedicels ranged from 7.2 to 26.9, 10.2 to 30.4 and 7.8 to 33.2 mm for spurs, short shoots and long shoots, respectively (Table 9). None of the bearing shoot types affected the flower number per cluster and spurs had fewer leaves per cluster than short and long shoots (Table 10). The average leaf area per cluster was significantly higher on short shoots compared to the spurs and long shoots (Table 10).

At commercial harvest, the L fruit had significantly heavier fruit pedicels, but did not differ significantly from K fruit in fruit size (weight, length and diameter), average fruit pedicel length and diameter or in number of well-developed seeds (Table 11). The range of pedicel lengths for K fruit was 5.5 to 24.8 and for lateral fruit slightly wider from 3.6 to 24.7 mm (Table 11). Both the average fruit weight and diameter were significantly higher on spurs compared to short shoots and the average fruit length was lower on short shoots compared to spurs and long shoots (Table 11). The number of well-developed seeds, average pedicel length and weight were lower on spurs than on short and long shoots (Table 11). The length of pedicels ranged from 3.6 to 23.7, 6.3 to 24.4 and 9.3 to 24.8 mm for spurs, short shoots and long shoots, respectively (Table 11)

## Discussion

*Flowers*. Flower position had little or no effect on the flower characteristics of all three cultivars. Studies by Prive et al. (1988) and Lombard (2000) reported that the pedicels of L flowers were longer than the K flowers in apple cultivars such as McIntosh, Spartan, Idared, Red Delicious and Royal Gala. Ferree et al. (2001) found concurring results in 'Jonagold' and 'Fuji' as the pedicel of the oldest L flower was longer than the pedicel of the K flower. Prive et al. (1988) found that pedicels of K flowers appear to be longer due to them being in the terminal position in the inflorescence. Our observations differ from the latter findings as the average pedicel length as well as the diameter, fresh weight and receptacle diameter of all three cultivars did not differ between L and K flowers. Prive et al. (1988) unfortunately referred to "pedicel lengths of lateral blooms", but it is not clear whether they also averaged the pedicel dimensions of all lateral flowers in the cluster as we did. The L flowers of 'Nicoter', 'Fuji', and 'Cripps' Pink', however, had a wider range in pedicel length than the K flowers (Table 1, 5 and 9), indicating a higher variability in pedicel length of L flowers.

In ‘Nicoter’ and ‘Cripps’ Pink’, the average flower pedicel length differed significantly on the bearing shoot types, with long shoots having the longest and spurs having the shortest pedicels. Lombard (2000) found the opposite on ‘Royal Gala’ as the average pedicel length of all flowers in a cluster on dorsal spurs were longer than those found terminally on long shoots. In ‘Fuji’, the flower pedicel length was not affected by the bearing shoot type, but the pedicel was significantly thinner on long shoots compared to short shoots and spurs. A similar result was found on ‘Royal Gala’ with the average pedicel diameter of all flowers in a cluster, terminally on long shoots, being lower compared to those formed on dorsal and ventral spurs (Lombard, 2000). The average leaf area per cluster of ‘Nicoter’ and ‘Fuji’ as well as the flower and leaf number per cluster in ‘Fuji’ progressively increased from spurs to short and long shoots. Rafael et al. (2012) found concurring results in ‘Gala’, ‘Daiane’ and ‘Fuji’. The leaf area per cluster in ‘Cripps’ Pink’, however, differed from the findings of Rafael et al. (2012) as it was significantly higher on the short shoots compared to the spurs and long shoots.

*Fruit.* Pedicel length and diameter did not differ between the K and L fruit of ‘Fuji’ and ‘Cripps’ Pink’. The effect of the bearing position in a cluster on the range of pedicel lengths were the opposite for fruit compared to what we found for flowers as K fruit had a higher range than the L fruit in all three cultivars, but the range was still very large. This effect of the K position was also evident in ‘Nicoter’ as the K fruit on the long shoots had significantly longer and heavier pedicels than the L fruit. In addition, the fruit size of ‘Nicoter’ apples was not affected by the K and L position in a cluster; therefore, the K position on long shoots yielded the longest pedicels. The average fruit size (weight, length and diameter) did not differ between the K and L fruit in ‘Cripps’ Pink’, while in ‘Fuji’, the K fruit were significantly longer and thicker than the L fruit when carried on short shoots. Ferree et al. (2001) and Jakopic et al. (2015) also reported that the K fruit of ‘Royal Gala’ and ‘Golden Delicious’ were larger than the L fruit. King flowers bloom earlier than L flowers in the same inflorescence and thus act as a sink earlier for assimilates therefore contributing to a larger final fruit size (Bangerth, 2000). However, the latter statement assumes that the K flowers set first as Bangerth (2000) reported that it is generally the fruit that set first and/or have the most seeds that become dominant.

Neither the fruit size of ‘Fuji’ and ‘Nicoter’, nor the pedicel size of ‘Fuji’ apples, was affected by the bearing shoot types alone. While the average pedicel diameter of ‘Nicoter’ fruit was thinner on long shoots compared to spurs, the average pedicel length and weight were only affected by an interaction between bearing shoot type and flower position. In 'Cripps' Pink', the flower pedicel length reflected in the fruit as both the average pedicel length and weight were greater on long and short shoots than on the spurs. Unfortunately, the pedicels of the flowers and fruit could not be correlated as it was from separate samples. Long shoots are thus a promising bearing position for longer pedicels in 'Cripps' Pink' as it had no detrimental effects on fruit size, whereas short shoots carried smaller fruit compared to spurs. Interestingly, the expected increase in fruit size with leaf area per cluster (Petri and Leite, 2004) was not found in these three cultivars. The opposite was actually found in 'Cripps' Pink' as short shoots had a higher average leaf area per cluster than spurs, but carried significantly smaller fruit compared to spurs.

## Conclusion

There was a large variation in the pedicel lengths of flowers and the subsequent fruit in all three cultivars. The cause of this variation is, however, still unclear as neither the flower position, nor the type of bearing shoot had marked effects on the pedicel size. Although the K position in clusters on long shoots of 'Nicoter' apples and long shoots in general on 'Cripps' Pink' were promising in terms of longer pedicel length, the number of bearing positions on long shoots will not be enough to maintain an economical yield. Further research is thus needed to identify the origin of the variation in pedicel lengths.

## Literature Cited


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

Dennis, F.G. 1986. Apple, p. 1-41. In: S.P. Monselise (ed.). CRC handbook of fruit set and development. 1st ed. CRC Press, Boca Raton, Flo.

Ferree, D.C., B.L. Bishop, J.R. Schupp, D.S. Tustin, and W.M. Cashmore. 2001. Influence of flower type, position in the cluster and spur characteristics on fruit set and growth of apple cultivars. J. of Hort. Sci. *Biotechnol*. 76(1):1-8.

Ferree, D.C., J.R. Schupp, D.S. Tustin, and W.M. Cashmore. 2000. Does 'king' dominance differ among apple cultivars and sites? Acta Hort. 527:27-34.

Hortgro, 2018. Key deciduous fruit statistics. www.hortgro.co.za

Jakopic, J., A. Zupan, K. Eler, V. Schmitzer, F. Stampar, and R. Veberic. 2015. It's great to be the King: Apple fruit development affected by the position in the cluster. Sci. Hort. 194:18–25.

Koutinas, N., G. Pepelyankov, and V. Lichev. 2010. Flower induction and flower bud development in apple and sweet cherry. Biotechnol. Biotechnol. Equip. 24(1):1549-1558.

Lombard, C. 2000. Fruit size improvement of 'Royal Gala' apples. Stellenbosch Univ., Stellenbosch, MScAgric. thesis

Miranda, C., L.G. Santesteban, and J.B. Royo. 2005. Removal of the most developed flowers influences fruit set, quality and yield of apple clusters. HortSci. 40(2):353-356.

Nothmann, J. and I. Rylski. 1983. Effects of floral position and cluster size on fruit development in eggplant. Sci. Hort. 19:19-24.

Petri, J.L. and G.B. Leite. 2004. Consequences of insufficient winter chilling on apple tree bud-break. Acta Hort. 662:53-60.

Prive, J.P., D.C. Elfving, and J.T.A. Proctor. 1988. Pedicel characteristics of four apple cultivars. Fruit Var. J. 42(4):122-125.

Rafael, H.M., F.G. Herter, and G.B. Leite. 2012. Influence of floral structure and flower bud quality on productivity and fruit shape in different apple cultivars. Rev. Bras. Frutic. 34(3):686-694.

Tomala, K. 1997. Orchard factors affecting nutrient content and fruit quality. Acta Hort. 448:257-264.

Tromp, J., H. Jonkers, and S. J. Wertheim. 1976. Grondslagen van de Fruitteelt. Staatsuitgeverÿ, 's-Gravenhage, The Netherlands.

Westwood, M.N., L.P. Batjer, and H.D. Billingsley. 1967. Cell size, cell number and fruit density of apples as related to fruit size, position in the cluster and thinning method. Proc. Amer. Soc. Hort. Sci. 91:51-62.

Wetzstein, H.Y., W. Yi., and J.A. Porter. 2013. Flower position and size impact ovule number per flower, fruit set, and fruit size in pomegranate. J. Amer. Soc. Hort. Sci. 138(3):159–166.

Table 1. Effect of different bearing shoot types and flower positions on flower characteristics of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2018/2019).

| | Average flower fresh weight (g) | | Average flower receptacle diameter (mm) | | Average pedicel length (mm) | | Range of pedicel length (mm) | Average pedicel diameter (mm) | |
|---|---|---|---|---|---|---|---|---|---|
| Bearing shoot type | | | | | | | | | |
| Spur | 0.15 | a | 2.28 | a | 16.51 | a | 9.45 – 30.25 | 1.21 | ns |
| Short shoot | 0.15 | a | 2.06 | b | 18.23 | b | 10.24 – 29.05 | 1.07 | |
| Long shoot | 0.12 | b | 2.53 | c | 19.62 | c | 10.81 – 30.63 | 1.12 | |
| Flower position | | | | | | | | | |
| King | 0.14 | ns | 2.31 | ns | 18.03 | ns | 9.69 – 29.48 | 1.16 | ns |
| Lateral* | 0.14 | | 2.27 | | 18.21 | | 9.45 – 30.63 | 1.11 | |
| *Significance level* | | | | | | | | | |
| *Bearing shoot type* | ***<.0001*** | | ***<.0001*** | | ***<.0001*** | | - | *0.0922* | |
| *Flower position* | *0.4687* | | *0.5510* | | *0.7129* | | - | *0.3136* | |
| *Bearing shoot*Flower position* | *0.2909* | | *0.5998* | | *0.9121* | | - | *0.5401* | |

* Average of all 4-5 lateral flowers in the cluster

Table 2. Effect of different bearing shoot types on the number of flowers and leaves, and leaf area in an inflorescence of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2018/2019).

| | Number of flowers per cluster | | Number of leaves per cluster | | Average leaf area per cluster ($cm^2$) | |
|---|---|---|---|---|---|---|
| Bearing shoot type | | | | | | |
| Spur | 5.76 | ns | 4.96 | ns | 13.07 | a |
| Short shoot | 5.84 | | 5.36 | | 18.69 | b |
| Long shoot | 5.64 | | 5.48 | | 23.34 | c |
| *Significance level* | *0.4445* | | *0.1876* | | ***<.0001*** | |

Table 3. Effect of different bearing shoot types and flower positions on the fruit size, pedicel size and seed number of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2018/2019).

| | Average fruit weight at 2019 harvest (g) | | Average fruit length at 2019 harvest (mm) | | Average fruit diameter at 2019 harvest (mm) | | Average pedicel diameter at 2019 harvest (mm) | | Range of pedicel length at 2019 harvest (mm) | Number of well-developed seeds per fruit | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bearing shoot type | | | | | | | | | | | |
| Spur | 94.64 | ns | 49.16 | ns | 61.67 | ns | 2.75 | a | 5.69 – 27.77 | 4.34 | ns |
| Short shoot | 100.24 | | 50.30 | | 63.05 | | 2.64 | ab | 5.59 – 27.86 | 4.55 | |
| Long shoot | 96.12 | | 49.53 | | 62.40 | | 2.51 | b | 8.96 – 29.69 | 4.86 | |
| Flower position | | | | | | | | | | | |
| King | 96.44 | ns | 49.82 | ns | 62.15 | ns | 2.67 | ns | 5.69 – 29.69 | 4.86 | a |
| Lateral* | 97.56 | | 49.50 | | 62.60 | | 2.59 | | 5.59 – 27.86 | 4.30 | b |
| *Significance level* | | | | | | | | | | | |
| *Bearing shoot type* | *0.2576* | | *0.2255* | | *0.1627* | | ***0.0371*** | | - | *0.2052* | |
| *Flower position* | *0.6979* | | *0.5624* | | *0.4436* | | *0.2926* | | **-** | ***0.0213*** | |
| *Bearing shoot*Flower position* | *0.5149* | | *0.2244* | | *0.6749* | | *0.5895* | | - | *0.3591* | |

* Average of all 4-5 lateral flowers in the cluster

Table 4. Effect of different bearing shoot types and flower positions on the average pedicel weight and length of 'Nicoter' apples at Alafontana, Vyeboom, South Africa (2018/2019).

| | Average pedicel length at 2019 harvest (mm) | | Average pedicel weight at 2019 harvest (g) | |
|---|---|---|---|---|
| Interaction (Bearing shoot type*Flower position) | | | | |
| Spur King | 15.31 | bc | 0.14 | b |
| Spur Lateral | 16.50 | ab | 0.17 | a |
| Short shoot King | 14.48 | c | 0.14 | b |
| Short shoot Lateral | 15.39 | bc | 0.15 | ab |
| Long shoot King | 17.51 | a | 0.17 | a |
| Long shoot Lateral | 14.96 | bc | 0.14 | b |
| *Significance level* | | | | |
| *Bearing shoot type* | *0.1127* | | *0.2378* | |
| *Flower position* | *0.7683* | | *0.4992* | |
| *Bearing shoot*Flower position* | ***0.0059*** | | ***0.0021*** | |

Table 5. Effect of different bearing shoot types and flower positions on flower characteristics of 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

| | Average flower fresh weight (g) | | Average flower receptacle diameter (mm) | | Average pedicel length (mm) | | Range of pedicel length (mm) | Average pedicel diameter (mm) | |
|---|---|---|---|---|---|---|---|---|---|
| Bearing shoot type | | | | | | | | | |
| Spur | 0.11 | a | 2.24 | a | 17.71 | ns | 9.26 – 28.64 | 0.99 | a |
| Short shoot | 0.12 | a | 2.21 | a | 18.15 | | 11.74 – 29.61 | 0.91 | a |
| Long shoot | 0.08 | b | 1.53 | b | 18.97 | | 9.83 – 29.84 | 0.71 | b |
| Flower position | | | | | | | | | |
| King | 0.11 | ns | 2.01 | ns | 18.38 | ns | 9.49 – 29.23 | 0.87 | ns |
| Lateral* | 0.10 | | 1.98 | | 18.17 | | 9.26 – 29.84 | 0.86 | |
| *Significance level* | | | | | | | | | |
| *Bearing shoot type* | ***<.0001*** | | ***<.0001*** | | *0.2164* | | - | ***0.0003*** | |
| *Flower position* | *0.4087* | | *0.7927* | | *0.7205* | | - | *0.8205* | |
| *Bearing shoot*Flower position* | *0.6776* | | *0.0674* | | *0.6717* | | - | *0.9758* | |

* Average of all 4-5 lateral flowers in the cluster

Table 6. Effect of different bearing shoot types on the number of flowers and leaves, and leaf area in an inflorescence of 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

| | Number of flowers per cluster | | Number of leaves per cluster | | Average leaf area per cluster ($cm^2$) | |
|---|---|---|---|---|---|---|
| Bearing shoot type | | | | | | |
| Spur | 4.76 | a | 5.16 | a | 18.08 | a |
| Short shoot | 5.56 | b | 6.32 | b | 31.19 | b |
| Long shoot | 6.28 | c | 8.40 | c | 39.94 | c |
| *Significance level* | ***<.0001*** | | ***<.0001*** | | ***<.0001*** | |

Table 7. Effect of different bearing shoot types and flower positions on the fruit weight, seed number and pedicel size of 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

| | Average fruit weight at 2019 harvest (g) | | Number of well-developed seeds per fruit | | Average pedicel length at 2019 harvest (mm) | | Range of pedicel length at 2019 harvest (mm) | Average pedicel diameter at 2019 harvest (mm) | | Average pedicel weight at 2019 harvest (g) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Bearing shoot type | | | | | | | | | | | |
| Spur | 103.96 | ns | 5.32 | ns | 11.42 | ns | 2.00 – 17.80 | 2.36 | ns | 0.08 | ns |
| Short shoot | 107.55 | | 5.44 | | 12.28 | | 4.39 – 22.62 | 2.47 | | 0.08 | |
| Long shoot | 103.99 | | 5.40 | | 12.43 | | 4.63 – 21.67 | 2.42 | | 0.07 | |
| Flower position | | | | | | | | | | | |
| King | 105.98 | ns | 5.40 | ns | 12.18 | ns | 2.00 – 22.62 | 2.40 | ns | 0.09 | a |
| Lateral* | 104.36 | | 5.38 | | 11.91 | | 4.39 – 21.67 | 2.43 | | 0.07 | b |
| *Significance level* | | | | | | | | | | | |
| *Bearing shoot type* | *0.6777* | | *0.9075* | | *0.1920* | | - | *0.4977* | | *0.0602* | |
| *Flower position* | *0.6716* | | *0.9442* | | *0.5888* | | - | *0.7767* | | ***0.0036*** | |
| *Bearing shoot*Flower position* | *0.0914* | | *0.8556* | | *0.4512* | | - | *0.5922* | | *0.6162* | |

* Average of all 4-5 lateral flowers in the cluster

Table 8. Effect of different bearing shoot types and flower positions on the average fruit diameter and length of 'Fuji' apples at Oak Valley, Elgin, South Africa (2018/2019).

| Interaction (Bearing shoot type*Flower position) | Average fruit length at 2019 harvest (mm) | | Average fruit diameter at 2019 harvest (mm) | |
|---|---|---|---|---|
| Spur King | 49.62 | ab | 61.13 | ab |
| Spur Lateral | 49.41 | b | 62.42 | ab |
| Short shoot King | 52.09 | a | 63.37 | a |
| Short shoot Lateral | 48.44 | b | 60.61 | b |
| Long shoot King | 49.23 | b | 60.99 | ab |
| Long shoot Lateral | 49.88 | ab | 61.94 | ab |
| *Significance level* | | | | |
| *Bearing shoot type* | *0.6376* | | *0.8344* | |
| *Flower position* | *0.1408* | | *0.8071* | |
| *Bearing shoot*Flower position* | ***0.0390*** | | ***0.0386*** | |

Table 9. Effect of different bearing shoot types and flower positions on flower characteristics of 'Cripps' Pink' apples at Applegarth, Grabouw, South Africa (2018/2019).

| | Average flower fresh weight (g) | | Average flower receptacle diameter (mm) | | Average pedicel length (mm) | | Range of pedicel length (mm) | Average pedicel diameter (mm) | |
|---|---|---|---|---|---|---|---|---|---|
| Bearing shoot type | | | | | | | | | |
| Spur | 0.13 | a | 2.33 | a | 16.54 | a | 7.24 – 26.91 | 1.06 | ns |
| Short shoot | 0.14 | ab | 2.25 | ab | 17.39 | ab | 10.23 – 30.37 | 0.99 | |
| Long shoot | 0.15 | b | 2.12 | b | 18.27 | b | 7.84 – 33.22 | 0.98 | |
| Flower position | | | | | | | | | |
| King | 0.14 | ns | 2.23 | ns | 17.60 | ns | 10.66 – 30.37 | 0.98 | ns |
| Lateral* | 0.14 | | 2.24 | | 17.20 | | 7.24 – 33.22 | 1.04 | |
| *Significance level* | | | | | | | | | |
| *Bearing shoot type* | ***0.0199*** | | ***0.0495*** | | *0.0568* | | **-** | *0.3719* | |
| *Flower position* | *0.5599* | | *0.9198* | | *0.5047* | | **-** | *0.2085* | |
| *Bearing shoot*Flower position* | *0.5883* | | *0.7037* | | *0.7443* | | - | *0.2444* | |

* Average of all 4-5 lateral flowers in the cluster

Table 10. Effect of different bearing shoot types on the number of flowers and leaves, and leaf area in an inflorescence of 'Cripps' Pink' apples at Applegarth, Grabouw, South Africa (2018/2019).

| | Number of flowers per cluster | | Number of leaves per cluster | | Average leaf area per cluster (cm$^2$) | |
|---|---|---|---|---|---|---|
| Bearing shoot type | | | | | | |
| *Spur* | 5.33 | ns | 5.42 | a | 29.81 | a |
| *Short shoot* | 5.58 | | 7.67 | b | 40.17 | b |
| *Long shoot* | 5.58 | | 7.00 | b | 33.05 | a |
| *Significance level* | *0.0630* | | ***<.0001*** | | ***0.0030*** | |

Table 11. Effect of different bearing shoot types and flower positions on the fruit and pedicel size and seed number of ‘Cripps’ Pink’ apples at Applegarth, Grabouw, South Africa (2018/2019).

| | Average fruit weight at 2019 harvest (g) | Average fruit length at 2019 harvest (mm) | Average fruit diameter at 2019 harvest (mm) | Number of well-developed seeds per fruit | Average pedicel length at 2019 harvest (mm) | Range of pedicel length at 2019 harvest (mm) | Average pedicel diameter at 2019 harvest (mm) | Average pedicel weight at 2019 harvest (g) |
|---|---|---|---|---|---|---|---|---|
| Bearing shoot type | | | | | | | | |
| Spur | 104.43 a | 54.76 a | 62.23 a | 4.76 b | 12.09 a | 3.56 – 23.68 | 2.64 ns | 0.10 a |
| Short shoot | 96.66 b | 53.50 b | 60.64 b | 5.50 a | 15.14 b | 6.33 – 24.42 | 2.41 | 0.14 b |
| Long shoot | 99.90 ab | 54.89 a | 61.44 ab | 5.34 a | 15.39 b | 9.29 – 24.82 | 2.49 | 0.14 b |
| Flower position | | | | | | | | |
| King | 98.63 ns | 54.14 ns | 61.09 ns | 5.27 ns | 13.96 ns | 5.47 – 24.82 | 2.47 ns | 0.12 a |
| Lateral* | 102.03 | 54.63 | 61.78 | 5.13 | 14.45 | 3.56 – 24.66 | 2.56 | 0.13 b |
| *Significance level* | | | | | | | | |
| *Bearing shoot type* | ***0.0183*** | ***0.0340*** | ***0.0171*** | ***0.0184*** | ***<.0001*** | - | *0.0724* | ***<.0001*** |
| *Flower position* | *0.1294* | *0.3135* | *0.1311* | *0.5189* | *0.3057* | - | *0.2735* | ***0.0103*** |
| *Bearing shoot*Flower position* | *0.8950* | *0.8614* | *0.5853* | *0.1055* | *0.6144* | - | *0.1125* | *0.4652* |

* Average of all 4-5 lateral flowers in the cluster

# PAPER 3: Reducing Cracking in 'Fuji' and 'Rosy Glow' Apples Using 6-Benzyladenine and Gibberellins ($GA_{4+7}$).

*Additional index words.* Fruit set, yield, fruit quality, fruit size, return bloom, cold storage.

---

***Abstract.***

**Fruit cracking is a major cosmetic defect that has become problematic in the Ceres region, the second biggest apple production region of South Africa. This disorder reduces fruit quality and therefore reduces the marketable yield and profitability. The aim of this study was to evaluate the efficacy of $GA_{4+7}$ to reduce 'Fuji' cracking and $GA_{4+7}$ + 6-BA to reduce 'Fuji' and 'Rosy Glow' cracking. In addition, the effect on fruit set, yield, fruit quality and return bloom was also evaluated to determine whether side-effects occurred. Three weekly (early) and bi-weekly (late) applications of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA, at three rates, were applied from seven until 35 days after full bloom. Unfortunately, due to specific weather conditions and adjustment of management practices, no cracking (pedicel- and calyx-end) was observed in the two seasons, except for small levels of pedicel-end cracking on 'Fuji' in the second season. In the first season, $GA_{4+7}$ at 20 and 40 $mg \cdot L^{-1}$ (early application) thinned 'Fuji' fruitlets and reduced the hand thinning requirement, but the total yield and yield efficiency per tree were not affected. The return bloom of 'Fuji' was reduced by all the $GA_{4+7}$ rates and decreased linearly with rate of the earlier $GA_{4+7}$ treatment. All the $GA_{4+7}$ + 6-BA rates (early and later applications) thinned 'Rosy Glow' fruitlets and 'Fuji' fruitlets were thinned by the highest $GA_{4+7}$ + 6-BA rate (3 x 40 $mg \cdot L^{-1}$), applied in weekly intervals. The total yield and yield efficiency per tree of both cultivars were, however, not affected by the combination treatment. The return bloom of 'Fuji' apples was reduced by all the $GA_{4+7}$ + 6-BA rates in the first season and decreased linearly with increasing rate of the later $GA_{4+7}$ + 6-BA applications in both seasons. Higher rates of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA should thus be used with caution when considered to control cracking.**

---

Fruit cracking is a major cosmetic defect that reduces fruit quality, thus reducing the marketable yield and profitability. Research indicates that important fruit types such as tomatoes (Peet, 1992), apricots (Gülsen et al., 1995), cherries (Belmans and Keulemans, 1996; Simon, 2006), apples and grapes (Ramteke et al., 2017) are subjected to this disorder. Apple cultivars susceptible to cracking include Cox's Orange Pippin (minute cracks on the uncolored side of fruit) (Goode et al., 1975), Stayman (unspecified) (Byers et al., 1990), Gala (internal ring cracking in fruit-pedicel joint) (Opara et al., 2000), Fuji (internal ring cracking in fruit-pedicel joint) (Kasai et al., 2008), 'Golden Delicious' (micro-cracking in the cuticular membrane) (Knoche et al. 2011) and Cripps' Pink (calyx-end ring cracking) (Stern et al., 2013).

The general belief is that apple cracks develop due to exposure to extreme conditions that cause growth stresses, especially during early fruitlet development (Taylor and Knight, 1986). Such conditions include extreme water relations (drought or oversupply of water) (Verner, 1938), temperature and relative humidity (high and low) (Kader, 1986; Tetley, 1930). While vigorous trees produce fruit that are less susceptible to cracking (De Salvador et al., 2006), factors such as low crop load (Shutak and Schrader, 1948) and a mineral imbalance (Opara et al., 2000) contribute to crack development. Verner (1938) found that these growing conditions, together with an uneven expansion rate between the inner and outer parts of the fruit, cause cracking.

Cracking became apparent in the Ceres region, the second biggest apple production region of South Africa (Hortgro, 2018), especially on 'Fuji' and 'Cripps' Pink'/ 'Rosy Glow' during the past few seasons (S. Reynolds, personal communication). 'Rosy Glow' apples developed calyx-end ring cracks, like the cracks described by Stern et al. (2013), while 'Fuji' apples developed small, concentric cracks at the pedicel-end.

Cracking is controlled by cultural practices such as pruning, scoring (Byers et al., 1990), improvement of the nutritional status (Powers and Bollen, 1947) and maintaining the optimal water supply (Goode et al., 1975). In addition, cracking is also controlled by plant growth regulators (PGRs) e.g. cytokinin and different gibberellins (GAs) (Byers et al., 1990; Ginzburg et al., 2014; Knoche et al., 2011; Stern et al., 2013; Taylor and Knight, 1986) as these stimulate cell division and promote cell enlargement, respectively (Al-Wir, 1978; Taiz and Zeiger, 2010; Wismer et al., 1995). These PGRs are used to improve the resistance of the peel to growth and environmental stresses (Ginzberg and Stern, 2016). In 'Golden Delicious' apples, micro-cracking in the cuticular membrane, stretching from the rim of the pedicel cavity to the calyx-end, was significantly reduced by four applications of 10 mg·L$^{-1}$ $GA_{4+7}$, applied in 10-day intervals from petal fall, by enlarging the epidermal and hypodermal cells (Knoche and Grimm, 2008; Knoche et al. 2011). Taylor and Knight (1986) reported that $GA_{4+7}$ caused an increase in peel plasticity of 'Cox', 'Discovery' and 'Golden Delicious' apples, thus alleviating the stress within the fruitlet. Cytokinins, like 6-benzyladenine (6-BA), are often considered as a mitigating option in combination with $GA_{4+7}$ (Cline, 2017; Leite et al., 2006; Stern et al., 2013). Promising results have been found on calyx-end cracking of 'Cripps' Pink' apples following three bi-weekly applications of 40 mg·L$^{-1}$ 6-BA + 40 mg·L$^{-1}$ $GA_{4+7}$ from 60 days after full bloom (d.a.f.b.) (Stern et al., 2013). Lower concentrations of the combination (5 mg·L$^{-1}$ 6-BA and 5 mg·L$^{-1}$ $GA_{4+7}$) were also effective if applied during the cell division period at seven, 21 and 35 d.a.f.b. (Ginzberg et al., 2014). Ginzberg et al. (2014) reported that the application of the combination during the cell division phase (seven to 35 d.a.f.b.) or cell expansion phase (60 to 90 d.a.f.b.) resulted in an increased epidermal cell density which increased the elasticity of the epidermal layer and subsequently reduced cracking. However, on 'Stayman Red' apples, 25 µl·L$^{-1}$ $GA_{4+7}$ + 6-BA applications at 35, 61, 76 and 109 days after full bloom (d.a.f.b.) were unsuccessful (Costa et al., 1983; Visai et al., 1989). The effectiveness of these treatments is thus subject to the concentration, timing and cultivar (Ginzberg and Stern, 2016).

The aim of this study was to evaluate the efficacy of different rates and timings of $GA_{4+7}$ on 'Fuji' cracking and $GA_{4+7}$ + 6-BA on 'Fuji' and 'Rosy Glow' cracking. In addition, the effect on fruit set, yield, fruit quality and return bloom was also evaluated to determine whether side-effects occurred.

## Materials and Methods

*Plant material and site description.* Two trials were conducted in the 2017/2018 season on 'Fuji' apples. Both trials were done on the farm Vastrap (33°14'55.2" S, 19°13'58.3" E) in the Witzenberg Valley near Ceres in the Western Cape, South Africa. The north-south oriented rows, on M7 rootstocks, were planted in 2007 at a spacing of 4 m x 1.75 m with 10% 'Granny Smith' trees as the cross-pollinator. In 2018/2019, trials were conducted on 'Fuji' and 'Rosy Glow' apples on the farm Welgemeen (33°11'15.9" S, 19°15'08.9" E) also in the Witzenberg Valley. The 'Fuji' trees, on M793 rootstocks, were planted in 2008 at a spacing of 4 m x 2 m with no cross pollinator.

The 'Rosy Glow' trees, also on M793 rootstocks, were planted in 2009 at a spacing of 4.5 m x 2 m with 40% 'Fuji' trees in alternating rows as cross pollinator. Experimental trees were selected based on uniformity with regards to size and flower density.

*Experimental layout and treatments.* In 2017/2018, two products, $GA_{4+7}$ (Regulex®; Valent BioSciences Corporation, Libertyville, Illinois 60048, USA) and $GA_{4+7}$ + 6-BA (Promalin®; Valent BioSciences Corporation, Libertyville, Illinois 60048, USA), were evaluated on 'Fuji'. Seven treatments as summarized in Table 1 and Table 2 were used. A randomized complete block design (RCBD) with ten single tree replicates was used. In 2018/2019 the PGR, $GA_{4+7}$ + 6-BA (Promalin®; Valent BioSciences Corporation, Libertyville, Illinois 60048, USA), was evaluated on 'Fuji' and 'Rosy Glow' apples. The experimental design used was a RCBD with ten single tree replicates. The same seven treatments as summarized in Table 1 were used.

*Treatment application: 2017/18 and 2018/2019 seasons.* All applications were done using a motorized backpack sprayer (STIHL, Pietermaritzburg, South Africa) at a rate of ±1000 $L{\cdot}ha^{-1}$. No surfactants were used, and drift effects were prevented by leaving at least one buffer tree between treated trees and a buffer row when more than one row was used. Weather details for the different spray periods during the two seasons are summarized in Fig. 1 and 2. An industry standard thinning program was performed on each cultivar. On 'Fuji' in 2017, NAA (5.6 $mg{\cdot}L^{-1}$ a.i.) + carbaryl (700 $mg{\cdot}L^{-1}$ a.i.) was applied between full bloom and seven d.a.f.b. followed with 6-BA (95 $mg{\cdot}L^{-1}$ a.i.) + carbaryl (700 $mg{\cdot}L^{-1}$ a.i.) between seven and 14 d.a.f.b. In 2018, carbaryl (576 $mg{\cdot}L^{-1}$ a.i.) was applied between seven and 14 d.a.f.b. on 'Fuji' and 'Rosy Glow'.

*Data collection.* See Paper 1 for data collection before harvest. At the main harvest, a sample of 30 fruit per tree was randomly selected and taken to the laboratory at Stellenbosch University. The following parameters were evaluated and recorded: fruit weight, -diameter and -length, pedicel-end russeting and calyx-end ribbing as described in Paper 1. In addition, retiform russeting and 'Fuji' cracking were scored according to the score cards presented in Fig. 3 and 4, respectively. Following the evaluations, the fruit were stored under regular atmosphere (RA) conditions for three months, where after cracking was scored again. An additional 50 fruit per tree from the main harvest were stored for three to four months in lug boxes under controlled atmosphere (CA) conditions (<1% $CO_2$ + 1.5% $O_2$) at 0.5 °C for 'Rosy Glow' and -0.5 °C for 'Fuji' apples. These fruit were subjected to evaluation after CA storage as described above. The ground color of all stored fruit was determined as an indication of maturity (Fig. 5) and return bloom was determined as described in Paper 1.

*Statistical analysis.* The data were analyzed using SAS Enterprise guide 7.1 (SAS Institute Inc., Cary, North Carolina, USA) using the linear model procedure and the pairwise t-test to determine the Least Significant Difference (LSD) when the F-statistic indicated significance at $P<0.05$. Single degree of freedom, orthogonal, polynomial contrasts were fitted where applicable.

## Results

*Results for the 2017/2018 season: 'Fuji' - $GA_{4+7}$ + 6-BA.* No pedicel-end cracks were found during the 2017/2018 season. Both the average fruit set per cluster on the two tagged branches and the average number of hand thinned fruitlets per tree decreased linearly with increasing rate of the earlier $GA_{4+7}$ + 6-BA applications, with only the highest rate (40 $mg \cdot L^{-1}$) applied seven, 14 and 21 d.a.f.b. significantly lower compared to the control (Table 3). The later $GA_{4+7}$ + 6-BA applications (seven, 21 and 35 d.a.f.b.) had no effect on set compared to the untreated control (Table 3).

On average, the PGR treatments increased the average fruit size at commercial harvest (weight, length and diameter) compared to the control (Table 4). No individual significant differences between treatments were found in the average fruit weight (Table 4). The average fruit length increased linearly with increasing rate of the earlier $GA_{4+7}$ + 6-BA applications, with 40 $mg \cdot L^{-1}$ significantly increasing length compared to the control (Table 4). Only the lowest rate of the later $GA_{4+7}$ + 6-BA treatments increased the fruit length compared to the control. Compared to the control, all the treatments except the early $GA_{4+7}$ + 6-BA at 10 $mg \cdot L^{-1}$ and the later $GA_{4+7}$ + 6-BA at 20 $mg \cdot L^{-1}$ increased the average fruit diameter (Table 4).

The percentage fruit with calyx-end ribbing increased quadratically with increasing rate of the earlier $GA_{4+7}$ + 6-BA with it not differing between 10 and 20 $mg \cdot L^{-1}$, but increasing from 20 to 40 $mg \cdot L^{-1}$. Ribbing also decreased quadratically with increasing rate of the later $GA_{4+7}$ + 6-BA applications, with it decreasing up to 20 $mg \cdot L^{-1}$. Both the early $GA_{4+7}$ + 6-BA at 40 $mg \cdot L^{-1}$ and the later $GA_{4+7}$ + 6-BA at 10 mg·L$^{-1}$ application significantly increased the calyx-end ribbing compared to the control (Table 5). The average ground color of the RA and CA stored fruit was increased (yellower) by the early $GA_{4+7}$ + 6-BA 40 mg·L$^{-1}$ and the later $GA_{4+7}$ + 6-BA 10 mg·L$^{-1}$ applications (Table 5). A linear increase was found in ground color in RA stored fruit following the earlier $GA_{4+7}$ + 6-BA applications. On average, all the treatments increased the ground color of CA-stored fruit compared to the control. Also, in CA stored fruit, the earlier applications on average resulted in a higher ground color score (yellower apples) compared to later applications. Data on pedicel-end and retiform russeting are not shown due to very low and non-significant results.

No significant differences were found in the total yield or yield efficiency per tree except that yield per tree increased linearly with increased rate of the later $GA_{4+7}$ + 6-BA treatments (Table 6). Compared to the control, all the treatments severely reduced the percentage return bloom on the two tagged branches, with return bloom decreasing linearly with increasing rate of the later $GA_{4+7}$ + 6-BA applications (Table 6).

*Results for the 2017/2018 season: 'Fuji' - $GA_{4+7}$.* No pedicel-end cracks were found during 2017/2018 season. No significant differences were found in the average fruit set per cluster on the two tagged branches (Table 7). However, the earlier $GA_{4+7}$ treatments caused a greater reduction on average in the hand thinning requirement per tree compared to the later $GA_{4+7}$ treatments (Table 7). Both the earlier 20 and 40 mg·L$^{-1}$ $GA_{4+7}$ treatments reduced the number of fruitlets that needed to be thinned by hand during commercial hand thinning compared to the control (Table 7). The number of hand thinned fruitlets decreased linearly with an increase in rate of the later $GA_{4+7}$ applications (Table 7).

The average fruit weight at harvest was not affected by any of the treatments, but the earlier $GA_{4+7}$ treatment on average led to a greater average length and diameter at commercial harvest than the later $GA_{4+7}$ treatment (Table 8). The earlier $GA_{4+7}$ applications at 10 and 40 mg·L$^{-1}$ increased the average fruit length compared to the untreated control, while the average fruit diameter decreased linearly with an increase in the rate of the later $GA_{4+7}$ treatments with the highest rate (40 mg·L$^{-1}$) leading to thinner fruit than the control (Table 8).

Calyx-end ribbing was increased by all the treatments, except for the later $GA_{4+7}$ 10 mg·L$^{-1}$ applications (Table 9). The earlier applications on average induced more calyx-end ribbing than the later applications. On average, all treatments increased the ground color (more yellow) of RA-stored fruit compared to the control. The average ground color score of the RA stored fruit showed a quadratic response to increasing rate of the earlier $GA_{4+7}$ treatments with the ground color being most yellow following the 20 mg·L$^{-1}$ treatment and the 20 and 40 mg·L$^{-1}$ rate yellower than the control. In contrast, ground color decreased linearly (i.e. become greener) with increasing rate of the later $GA_{4+7}$ treatments (Table 9). None of the treatments affected the average ground color of the CA stored fruit. Data on pedicel-end and retiform russeting are not shown due to very low and non-significant results.

None of the treatments had a significant effect on the total yield or yield efficiency per tree (Table 10). The $GA_{4+7}$ significantly reduced the percentage return bloom on the two tagged branches (p=0.0001) compared to the untreated control and it decreased linearly with increasing rate of the earlier $GA_{4+7}$ applications (Table 10).

*Results for the 2018/2019 season: 'Fuji'*. No statistical differences were found in the average fruit set per cluster on the two tagged branches nor in the number of fruitlets that needed to be thinned by hand per tree following $GA_{4+7}$ + 6-BA applications (Table 11). On average, the earlier $GA_{4+7}$ + 6-BA treatments increased the average fruit size (weight, length and diameter) at commercial harvest compared to the later $GA_{4+7}$ + 6-BA treatments (Table 12). No significant differences were found in the average fruit weight and only the later $GA_{4+7}$ + 6-BA applications at 20 mg·L$^{-1}$ reduced the average fruit length compared to the control. The average fruit diameter was not altered by the earlier $GA_{4+7}$ + 6-BA applications, but all the later $GA_{4+7}$ + 6-BA rates significantly decreased it compared to the control, thus reducing the fruit diameter overall for the treatments compared to the untreated control (Table 12).

No stem-end cracks were found at harvest or in the RA stored fruit. In the CA stored fruit, the average crack score was on average reduced by the $GA_{4+7}$ + 6-BA treatments compared to the untreated control (p=0.0148). However, the percentage fruit with cracks (any score other than 0) was not affected by any of the treatments except for a linear increase with increasing rate of the later $GA_{4+7}$ + 6-BA treatments (Table 13). Each of the $GA_{4+7}$ + 6-BA treatments significantly decreased the percentage CA stored fruit with an average crack score of higher than one compared to the control (p=0.0011) (Table 13). On average, treatments increased the percentage fruit with calyx-end ribbing compared to the control. Ribbing increased more with the later than with the earlier $GA_{4+7}$ + 6-BA treatments. Calyx-end ribbing was significantly increased by all the rates of the later $GA_{4+7}$ + 6-BA treatment compared to the control (Table 13). The $GA_{4+7}$ + 6-BA treatments on average resulted in higher ground color scores (yellower apples) after RA storage compared to the untreated control while later treatments also resulted in higher average scores compared to earlier applications (Table 13). After CA storage, early treated fruit showed a quadratic response in ground color with fruit from trees treated with 20 $mg \cdot L^{-1}$ $GA_{4+7}$ + 6-BA having significantly higher scores (yellower apples) compared to all other treatments and the control (Table 13). Data on pedicel-end and retiform russeting are not shown due to very low and non-significant results

No significant differences were found in the total yield efficiency per tree, but the earlier $GA_{4+7}$ + 6-BA treatment did result in an overall higher yield per tree compared to the later $GA_{4+7}$ + 6-BA treatments (Table 14). The percentage return bloom decreased linearly with increasing rate of the later applied $GA_{4+7}$ + 6-BA (Table 14). None of the individual treatments altered the return bloom percentage.

*Results for the 2018/2019 season: 'Rosy Glow'.* No calyx-end cracks were found during the 2018/2019 season. The average fruit set per cluster on the two tagged branches decreased linearly with an increase in rate of the later $GA_{4+7}$ + 6-BA treatments with only the highest rate significantly lower compared to the untreated control (Table 15). All the treatments reduced the number of fruitlets that had to be thinned by hand (Table 15). On average, the average fruit size at commercial harvest (weight, length and diameter) was increased by the PGRs compared to the untreated control (Table 16). The 20 and 40 $mg \cdot L^{-1}$ of both the earlier and later $GA_{4+7}$ + 6-BA applications increased the average fruit weight and length compared to the control (Table 16). Also, the fruit weight and length increased linearly with increasing rate of the earlier $GA_{4+7}$ + 6-BA applications. All the individual treatments increased the average fruit diameter compared to the control (Table 16).

Calyx-end ribbing increased linearly with increasing rate of the earlier $GA_{4+7}$ + 6-BA treatments, but was generally very low (Table 17). The average ground color of the RA stored fruit was not affected and only 10 $mg \cdot L^{-1}$ late $GA_{4+7}$ + 6-BA caused a small, but significant increase (more yellow) in the ground color compared to the control of the CA stored fruit (Table 17). A linear increase in ground color score (more yellow) was found following the early and a decrease (greener) was found following late applications of CA stored fruit. Also, on average, earlier applications resulted in lower ground color scores (greener apples) compared to late applications. Data on pedicel-end and retiform russeting are not shown due to very low and non-significant results. No significant differences were found in the total yield efficiency per tree, but a linear increase was found in the yield with increasing rate of the early $GA_{4+7}$ + 6-BA applications (Table 18). On average the $GA_{4+7}$ + 6-BA treatments reduced return bloom percentage, but treatments did not differ from each other (Table 18).

## Discussion

No pedicel-end cracks were found at harvest on ‘Fuji’ in both seasons, nor calyx-end cracks in ‘Rosy Glow’ apples during one season. This was unexpected as these orchards were chosen for the trials as they were prone to fruit cracking during previous seasons. This phenomenon can probably be attributed to amongst others a weather effect. The Western Cape suffered an extreme drought in 2016 and 2017 (Vogel and van Zyl, 2016) which limited the available water for irrigation and trees were stressed (S. Reynolds, personal communication). This stress possibly reduced the rate of flower differentiation (Brown and Abi-Fadel, 1953), causing some flowers to have fewer cells at full bloom and thus being more sensitive to sudden increases in fruit growth rate. In addition, low spring temperatures during the early development of the apples could have also added to the stress by limiting cell division. Warrington et al. (1999) found that the mean diameter expansion rate of ‘Fuji’, ‘Golden Delicious’, ‘Red Delicious’ and ‘Braeburn’ was at least eight times lower at a 9/3 ºC regime than at 25/15 ºC during the cell division phase (10 to 40 d.a.f.b.). Any exposure to rainfall prior to harvest could thus have led to cracks as cracking occurs when an excessive amount of water is absorbed at a late stage of fruit development following a period of drought that limited fruit growth (Verner, 1938). According to the growers at Vastrap and Welgemeen, water resources were replenished in 2018 and 2019 to an extent where they could irrigate optimally, especially during the rapid growth period prior to harvest. In addition, no extreme weather conditions were present during our trials, thus explaining a possible reason for the absence of fruit cracking.

‘Fuji’ apples did, however, develop some small, concentric pedicel-end cracks after three months CA storage during the 2018/2019 season. Knoche and Grimm (2008) found similar results on 'Golden Delicious' as micro-cracking on the cuticle increased significantly after storing fruit for 113 days at 2 ± 0.5 °C and 92 ± 2% relative humidity (RH). Crack development during storage can be due to the high RH that limits the reduction in fruit weight and firmness, but decreases transpiration (Prange et al., 2001) that can increase cracking (Lee et al., 2019). The fruit size at Welgemeen farm was substantially larger in the 'Fuji' apples in the 2018/2019 season compared to the 'Fuji' apples from Vastrap in 2017/2018 season (Table 4 and 12). This could have resulted in the 10-17.5% fruit cracking during the second season as a strong relationship between cracking incidence and severity and fruit size was found in 'Royal Gala' apples (Lee et al., 2013). In addition, these large 'Fuji' apples were more mature as indicated by the post-storage ground color (yellower color) than the apples of the previous season, therefore another possible contributing factor as fruit ripening is associated with cell wall solubilization that weakens the integrity of the epidermal and hypodermal cells (Lee et al., 2019; Roth et al., 2005). Although the $GA_{4+7}$ + 6-BA treatments did not have a huge effect on fruit cracking, as very little cracking was present after CA storage, it generally reduced the average crack score and the percentage fruit with a crack score higher than one, compared to the untreated control. The combination of $GA_{4+7}$ and 6-BA in our trials was applied at an early and later stage of the cell division period and therefore the latter results concur with Ginzberg et al. (2014), who found that lower concentrations of $GA_{4+7}$ + 6-BA (5 $mg \cdot L^{-1}$ 6-BA and 5 $mg \cdot L^{-1}$ $GA_{4+7}$) reduced calyx-end cracking of 'Cripps' Pink' apples when applied at seven, 21 and 35 d.a.f.b (i.e. during the cell division period). Stern et al. (2013) attributed the success of $GA_{4+7}$ + BA to an increased epidermal cell density and peel flexibility. Due to the very low level of cracking and cracking only being present after CA storage in 'Fuji' in one season, very little can be said regarding the efficacy of the treatments. Irrespective of the cracking results, we still evaluated the treatment effect on fruit set, yield, fruit quality and return bloom to determine whether side-effects occurred.

*$GA_{4+7}$*. During the first season, the average number of fruitlets that had to be thinned by hand decreased linearly with increasing rate of the later $GA_{4+7}$ applications and was significantly lower with the earlier $GA_{4+7}$ treatment at 20 and 40 $mg \cdot L^{-1}$. Although no significant differences were found in the average fruit set per cluster, the negative effect of the higher $GA_{4+7}$ rates on set was clear in the hand thinning requirement. It is important to note that the fruit set data was only recorded on two branches per tree, whereas the hand thinning requirement included the entire tree.

Gibberellins are generally known to increase fruit set (Greene, 1989), but several studies, including ours, found the opposite. Looney et al. (1992) found that four weekly applications of $GA_{4+7}$ 15 $mg·L^{-1}$ from petal fall also reduced the fruit set on ‘Golden Delicious’ and ‘Cox’s Orange Pippin’. Edgerton (1981) proposed that the reduced fruit set is due to induced ethylene production in ‘Golden Delicious’ apple shoots following a post bloom $GA_{4+7}$ 100 $mg·L^{-1}$ application. We did not monitor vegetative shoot growth, but it is known that GAs induce internode elongation and shoot growth (Atay and Koyuncu, 2016; Müller and Theron, 2018; Paper 1; Taylor, 1978), thus reducing fruit set. The total yield and yield efficiency per tree and average fruit weight were not affected by any of the treatments. The average fruit length and diameter were, however, higher with the earlier $GA_{4+7}$ treatment compared to the later $GA_{4+7}$ treatment with earlier $GA_{4+7}$ at 10 and 40 $mg·L^{-1}$ causing a small, but significant increase in the length. Wertheim (1973) also found that an early (before 20 d.a.f.b.) $GA_{4+7}$ application at 100 $mg·L^{-1}$ increased the fruit length of ‘Cox’s Orange Pippin’ apples. Gibberellin $A_{4+7}$ increased the percentage fruit with calyx-end ribbing and it was overall higher on trees treated with the earlier $GA_{4+7}$ applications than the later treatments. Calyx-end ribbing is a common consequence of the PGRs, cytokinin and gibberellin, as they stimulate cell division and promote cell enlargement, respectively (Modlibowska, 1972). The ribbing in our trials was classified as present even when barely visible (Fig. 8 Paper 1); therefore, the increase in this malformation has no consequence. The return bloom was significantly lower in all the treatments compared to the control and decreased linearly with early $GA_{4+7}$ rate. Several studies have found that $GA_{4+7}$ inhibit flower induction and subsequently reduce the return bloom in the following season (Davis, 2002; Looney et al., 1992; Marino and Greene, 1981; Tromp, 1982) Due to the detrimental effect on return bloom, $GA_{4+7}$ was omitted as treatment during the second season.

*$GA_{4+7}$ + 6-BA.* The fruit set and number of fruitlets that had to be thinned by hand of ‘Fuji’, in the first season, and ‘Rosy Glow’, in the second season were reduced by the combination of $GA_{4+7}$ and 6-BA. The set and hand thinning requirement of the ‘Fuji’ apples decreased linearly with increasing rate of the earlier $GA_{4+7}$ + 6-BA treatment with the highest rate significantly lower than the control. On ‘Rosy Glow’, the later $GA_{4+7}$ + 6-BA treatment at 40 $mg·L^{-1}$ reduced the set and all the treatments reduced the hand thinning requirement compared to the control. Although $GA_{4+7}$ can decrease fruit set as discussed above, this reduction in set and hand thinning requirement

can probably primarily be attributed to the 6-BA component of the combination treatments. Benzyladenine is a known chemical thinner of apple fruitlets at 8- 12 mm diameter (Bound, 2001; Bound et al., 1991; Greene et al., 1990; Williams and Fallahi, 1999; Yuan and Greene, 2000) by inhibiting leaf photosynthesis (Stopar et al., 2001; Yuan and Greene, 2000), stimulating vegetative growth (Schröder and Bangerth, 2006), and increasing ethylene production which leads to abscission (Dal Cin et al., 2007). Greene and Autio (1989) found that 6-BA can thin 'McIntosh' apple flowers at rates as low as 25 mg·L$^{-1}$. Promalin® ($GA_{4+7}$ + 6-BA) is a registered thinning agent in South Africa for 'Golden Delicious', 'Granny Smith' and 'Royal Gala' apples and 14 d.a.f.b., i.e. a time within our application period, is the second application stage in the registration, thus further supporting the thinning effect we found. It is interesting to note that although $GA_{4+7}$ + 6-BA is registered to thin apple fruitlets of eight to 10 mm (14 d.a.f.b.), pre-bloom applications of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA at pink bud, seven and 14 days after pink bud and at rates as low as 10 mg·L$^{-1}$ also thinned 'Nicoter' and 'Cripps' Pink' flowers (Paper 1). No side-effects were found with the pre-bloom applications, except for a lower yield and yield efficiency with 20 mg·L$^{-1}$ $GA_{4+7}$ + 6-BA on 'Cripps' Pink' apples. It could thus be worthwhile to evaluate $GA_{4+7}$ and $GA_{4+7}$ + 6-BA as pre-bloom thinners of apples as the earlier thinning would possibly result in larger fruit.

During the 2017/2018 season, the fruit length of the 'Fuji' apples was increased by the early and later $GA_{4+7}$ + 6-BA treatment, at 40 mg·L$^{-1}$ and 10 mg·L$^{-1}$, respectively. All the rates except the early $GA_{4+7}$ + 6-BA at 10 mg·L$^{-1}$ and later $GA_{4+7}$ + 6-BA 20 mg·L$^{-1}$ increased the average diameter. The effect on the fruit size of 'Rosy Glow' in the second season was more pronounced as increasing rates of the early and later $GA_{4+7}$ + 6-BA treatment resulted in a linear increase in the weight and length with 20 mg·L$^{-1}$ and 40 mg·L$^{-1}$ higher than the control. Also, all the $GA_{4+7}$ + 6-BA rates increased the diameter compared to the control. It is well-known that the combination of $GA_{4+7}$ and 6-BA is used to improve apple fruit shape and -size by stimulating cell division and enlargement (Burak and Büyükyilmaz, 1998; Greene; 2002; Wismer et al., 1995). In addition to the direct effect of the PGR on fruit size and shape, the thinning on the two cultivars most probably added to the increased fruit size (Link, 2000). The thinning effect can thus be seen as positive as it possibly decreased the time required for hand thinning and thus labor cost, while increasing the fruit size and not reducing the total yield nor yield efficiency per tree in all the trials. The effect of $GA_{4+7}$ + 6-BA on fruit shape was also reflected in the calyx-end ribbing on the 'Fuji' apples of both seasons as it generally increased with all the rates compared to the control. The ribbing was, however, very mild as indicated before and not of any concern. In the second season, 'Fuji' apples were shorter with later $GA_{4+7}$ + 6-BA at 20 mg·L$^{-1}$ and thinner with both 20 and 40 mg·L$^{-1}$ compared to all the early $GA_{4+7}$ + 6-BA rates and the untreated control. This phenomenon cannot be explained.

A notable side-effect of the combination was found in the first season when the return bloom of the 'Fuji' apples was lower at all the rates compared to the control and decreased linearly with increasing rate of the later $GA_{4+7}$ + 6-BA applications. As stated above, the $GA_{4+7}$ component of the combination is a known inhibitor of flower induction. Although the return bloom of the 'Fuji' apples in the second season decreased linearly with increasing rate of the later $GA_{4+7}$ + 6-BA applications, no significant differences were found in the 2018/2019 season on the 'Fuji' and 'Rosy Glow' apples. 6-BA counteracts the inhibitory effect $GA_{4+7}$ has on flower induction (Ramírez and Hoad, 1981) and can thus explain the absence of a significantly reduced return bloom in the second season. The ability of 6-BA to counteract the effect of GA is supported by Bound et al. (1991) as they found that 50 mg·L$^{-1}$ BA increased the return bloom of 'Red Fuji' apples if applied at 20 d.a.f.b. The reason for the variable effects on return bloom between the two seasons is, however, unclear. Tromp (1982) suggested that the year-to-year variations in endogenous hormone levels between trees and cultivars might explain the variable responses of apple trees towards PGRs.

## Conclusion

Unfortunately, due to specific weather conditions and adjustment of management practices, no cracking (pedicel- and calyx-end) was observed in either season, except for low levels (10-17.5%) after CA storage on 'Fuji' in the second season. Due to the very low level of cracking, very little can be said regarding the efficacy of the PGR treatments. The results did, however, indicate that higher rates of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA should be used with caution as the fruit set and return bloom of 'Fuji' were reduced by both, while $GA_{4+7}$ + 6-BA decreased the set of 'Rosy Glow' apples.

## Literature Cited


Al-Wir, A.I. 1978. The influence of growth regulators on the anatomical, morphological development and quality of apple fruits. Iowa State Univ., Ames, Iowa, USA, PhD Diss.

Atay, A.N. and F. Koyuncu. 2016. Manipulating regular bearing in ‘Golden Delicious’/M9 apple trees using $GA_{4+7}$ and ethephon, Int. J. of Fruit Sci. 16(1):10-22.

Belmans, K. and J. Keulemans. 1996. A study of some fruit skin characteristics in relation to the susceptibility of cherry fruit to cracking. Acta Hort. 410:547–550.

Bound, S.A. 2001. The influence of endothall and 6-benzyladenine on crop load and fruit quality of red ‘Delicious’ apple. J. of Hort. Sci. and Biotechnol. 76(6):691-699.

Bound, S.A., K.M. Jones, T.B. Koen, and M.J. Oakford. 1991. The thinning effect of benzyladenine on red ‘Fuji’ apple trees. J. of Hort. Sci. 66(6):789-794.

Brown, D. S. and J.F. Abi-Fedel. 1953. The stage of development of apricot flower buds in relation to their chilling requirement. J. Am. Soc. Hort. Sci. 61:110-118.

Burak, M. and M. Büyükyilmaz. 1998. Effect of promalin on fruit shape and quality of ‘Starking Delicious’ apple cultivar. Acta Hort. 463:365-370.

Byers, R.E., D.H. Carbaugh, and C.N. Presley. 1990. 'Stayman' fruit cracking as affected by surfactants, plant growth regulators and other chemicals. J. Amer. Soc. Hort. Sci. 115(3):405-411.

Cline, J.A. 2017. Interactive effects of 6-BA, GA4+7, and prohexadione-calcium on Gala apples. Can. J. of Plant Sci. 97(4):632-644.

Costa, G., C. Giulivo, and A. Ramina. 1983. Influence of growth regulators on apple fruit cracking (cv. ‘Stayman Red’. Acta Hort. 137:366-369 (abstr.).

Dal Cin, V., A. Boschetti, A. Dorigoni, and A. Ramina. 2007. Benzylaminopurine application on two different apple cultivars (*Malus domestica*) displays new and unexpected fruitlet abscission features. Ann. Bot. 99:1195-1202.

Davis, D.E. 2002. Inhibition of flower bud initiation and development in apple by defoliation, gibberellic acid and crop load manipulation. Virginia Polytechnic Institute and State Univ., Blacksburg, Virginia, USA, PhD Diss.

De Salvador, F.R., M. Fisichella and M. Fontanari. 2006. Correlations between fruit size and fruit quality in apple trees with high and standard crop load levels. J. Fruit Ornam. Plant Res. 14:113-122.

Edgerton, L.J. 1981. Some effects of aminoethoxyvinylglycine, 6-benzylamino purine and gibberellins on fruit set and vegetative growth of apple. Acta Hort. 120:125-130.

Ginzberg, I. and R.A. Stern. 2016. Strengthening fruit-skin resistance to growth strain by application of plant growth regulators. Sci. Hort. 198:150-153.

Ginzberg, I., E. Fogelman, L. Rosenthal, and R.A. Stern. 2014. Maintenance of high epidermal cell density and reduced calyx-end cracking in developing 'Pink Lady' apples treated with a combination of cytokinin 6-benzyladenine and gibberellins $A_4$+$A_7$. Sci. Hort. 165:324-330.

Goode, J.E., M.M. Fuller, and K.J. Hyrycz. 1975. Skin-cracking of Cox's Orange Pippin apples in relation to water stress. J. Hort. Sci. 50:265-269.

Greene, D.W. 1989. Gibberellins $A_{4+7}$ influence fruit set, fruit quality and return bloom of apples. J. Am. Soc. Hort. Sci. 114(4):619-625.

Greene, D.W. 2002. Development of new plant growth regulators from a university perspective. HortTech. 12:71-74.

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

Greene, D.W., W.R. Autio, and P. Miller. 1990. Thinning activity of benzyladenine on several apple cultivars. J. Amer. Soc. Hort. Sci. 115(3):394-400.

Gülsen, Y., H. Dumanoğlu, and B. Kunter. 1995. Fruit cracking in some Turkish apricot cultivars. Acta Hort. 384:277–282.

Hortgro, 2018. Key deciduous fruit statistics. www.hortgro.co.za

Kader, A.A. 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. Food technol. 40(5):99-104.

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

Knoche, M. and E. Grimm. 2008. Surface moisture induces microcracks in the cuticle of 'Golden Delicious' apple. HortSci. 43:1929–1931.

Knoche, M., B.P. Khanal, and M. Stopar. 2011. Russeting and microcracking of 'Golden Delicious' apple fruit concomitantly decline due to Gibberellin $A_{4+7}$ application. J. Amer. Soc. Hort. Sci. 136(3):159-164.

Lee, J., J.P. Mattheis, and D.R. Rudell. 2013. Fruit size affects physiological attributes and storage disorders in cold-stored ‘Royal Gala’ apples. HortSci. 48(12):1518-1524.

Lee, J., J.P. Mattheis, and D.R. Rudell. 2019. High storage humidity affects fruit quality attributes and incidence of fruit cracking in cold-stored ‘Royal Gala’ apples. HortSci. 54(1):149-154.

Leite, G.B., J.L. Petri, and C. Basso. 2006. Promalin effect on ´Imperial Gala´ and ‘Fuji’ apple trees fructification. Acta Hort. 727:269-278.

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

Looney, N.E., R. L. Granger, C. L. Chu, S. J. Mcartney, L. N. Mander, and R.P. Pharis 1992. Influences of gibberellins A4, A4+7, and A4+iso—A7 on apple fruit quality and tree productivity. I. Effects on fruit russet and tree yield components. J. of Hort. Sci. 67(5): 613-618

Marino, F. and D.W. Greene. 1981. Involvement of gibberellins in the biennial bearing of apples *Malus domestica* cv. Early McIntosh. J. Am. Soc. Hort. Sci. 106(5):593-596.

Modlibowska, I. 1972. The effect of gibberellins and cytokinins on fruit development of Bramley’s Seedling apple. J. of Hort. Sci. 47(3):337-340.

Müller, A.M. and K.I. Theron. 2018. The use of plant growth regulators to increase apical extension growth of first-leaf apple trees. XIth International symposium on integrating canopy, rootstock and environmental physiology in orchard systems. Acta Hort. 1228:359-362.

Opara, L.U., A.J. Hodson, and C.J. Studman. 2000. Pedicel-end splitting and internal ring-cracking of 'Gala' apples as influenced by orchard management practices. J. of Hort. Sci. and Biotechnol. 75(4):465-469.

Peet. M.M. 1992. Radial fruit cracking in tomato. HortTechnol. 2:216–223.

Powers, W.L. and W.B. Bollen. 1947. Control of cracking of fruit by rain. Science 105:334-335.

Prange, R.K., J.M. DeLong, and P.A. Harrison. 2001. Storage humidity and post-storage handling temperature affect bruising and other apple quality characteristics. Acta Hort. 553:717–720.

Ramírez, H. and Hoad, G.V. 1981. Effects of growth substances on fruit-bud initiation in apple. Acta Hort. 120:131-136.

Ramteke, S.D., V. Urkude, S.D. Parhe, and S.R. Bhagwat. 2017. Berry cracking; its causes and remedies in grapes - a review. Trends in Biosci. 10(2):549-556.

Roth, E., E. Kovacs, M. Hertog, and E. Vanstreels. 2005. Relationship between physical and biochemical parameters in apple softening. Acta Hort. 682:573-578.

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

Shutak, V., and A.L. Schrader. 1948. Factors associated with skin-cracking of York Imperial apples. Proc. Am. Soc. Hort. Sci. 51:245-257.

Simon, G. 2006. Review on rain induced fruit cracking of sweet cherries (Prunus avium L.), its causes and the possibilities of prevention. Intl. J. of Hort. Sci. 12(3):27-35.

Stern, R., R. Ben-Arie, and I. Ginzberg. 2013. Reducing the incidence of calyx cracking in 'Pink Lady' apple using a combination of cytokinin (6-benzyladenine) and gibberellins ($GA_{4+7}$). J. of Hort. Sci. and Biotechnol. 88(2):147–153.

Stopar, M., M. Resnik, and V.Z. Pongrac. 2001. Non-structural carbohydrate status and $CO_2$ exchange rate of apple fruitlets at the time of abscission influenced by shade, NAA or BA. Scientia Hort. 87:65-76.

Taiz, L., E. Zeiger. 2010. Plant physiology, 5$^{th}$ ed. Sinauer Associates, Sunderland.

Taylor, D.R. and J.N. Knight.1986. Russeting and cracking of apple fruit and their control with plant growth regulators. Acta Hort. 179:819-820 (abstr.).

Taylor, K. 1978. Effects of gibberellin sprays on fruit russet and tree performance of 'Golden Delicious' apple. J. of Hort. Sci. 53(3):167-169.

Tetley, U. 1930. A study of the anatomical development of the apple and some observations on the pectic constituents of the cell walls. J. Pomol. Hort. Sci. 8:153-171.

Tromp, J. 1982. Flower-bud formation in apple as affected by various gibberellins. J. of Hort. Sci. 57(3):277-282.

Verner, L. 1938. Histology of apple fruit in relation to cracking. J. Agr. Res. 5:813-824.

Visai, C., O. Failla, and T. Eccher. 1989. Effects of promalin and paclobutrazol on cracking and quality of 'Niepling Stayman' apples. Acta Hort. 239:451-453 (abstr.).

Vogel, C. and K. van Zyl. 2016. Drought: In Search of sustainable solutions to a persistent, 'wicked' problem in South Africa, p. 195-211. In: N. Salzmann, C. Huggel, S. Nussbaumer, and G. Ziervogel (eds.). Climate change adaptation strategies – An upstream-downstream perspective. Springer, Cham.

Warrington, I.J., T.A. Fulton, E.A. Halligan, and H.N. de Silva. 1999. Apple fruit growth and maturity are affected by early season temperatures. J. Amer. Soc. Hort. Sci. 124(5):468–477.

Wertheim, S.J. 1973. Fruit set and June drop in Cox's Orange Pippin apple affected by pollination and treatment with a mixture of gibberellins $A_4$ and $A_7$. Sci. Hort. 1:85-105.

Williams, K.M. and E. Fallahi. 1999. The effects of exogenous bioregulators and environment on regular cropping of apple. HortTech. 9(3):323-327.

Wismer, P.T., J.T.A. Proctor, and D.C. Elfving. 1995. Benzyladenine affects cell division and cell size during apple fruit thinning. J. Amer. Soc. Hort. Sci. 120(5):802-807.

Yuan, R. and D.W. Greene. 2000. Benzyladenine as a chemical thinner for 'McIntosh' apples. I. Fruit thinning effects and associated relationships with photosynthesis, assimilate translocation and nonstructural carbohydrates. J. Amer. Soc. Hort. Sci. 125(5):169-176.

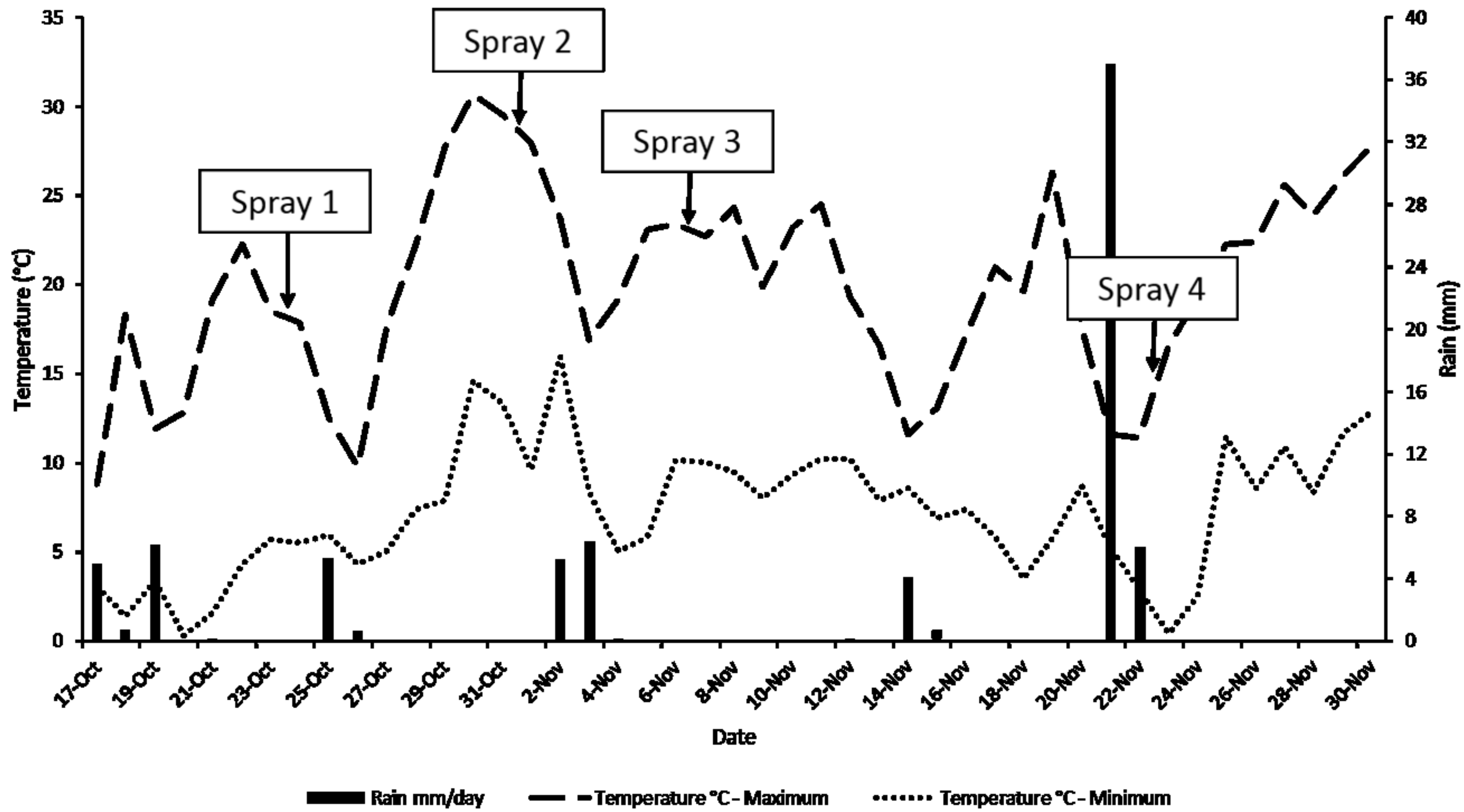


Fig. 1. Weather data for the 2017 spray period on 'Fuji' apples at Vastrap, Witzenberg valley, South Africa.

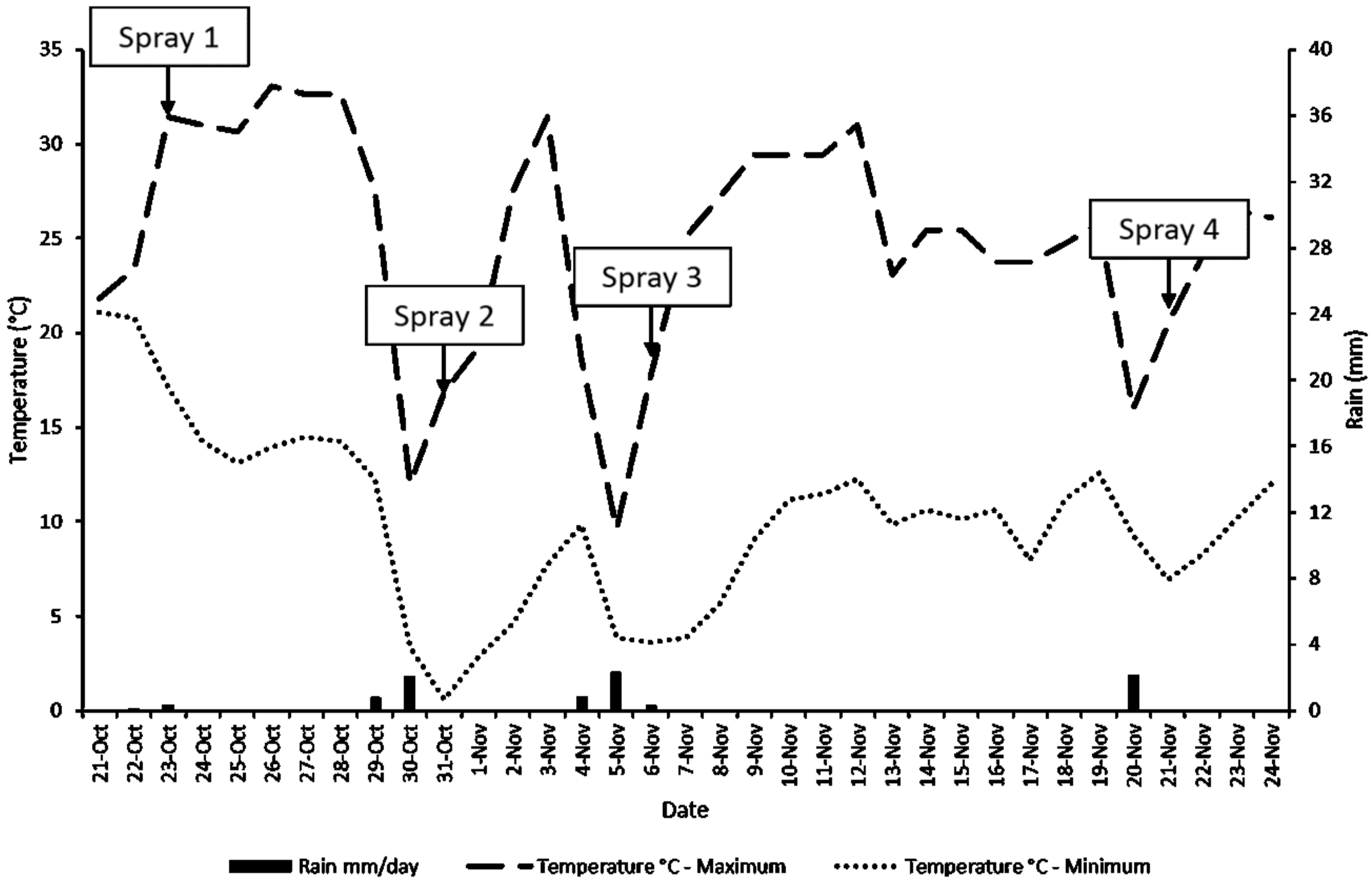


Fig. 2. Weather data for the 2018 spray period on ‘Fuji’ and ‘Rosy Glow’ apples at Welgemeen, Witzenberg valley, South Africa.


Fig. 3. Scale used to score retiform on apples. Deciduous Fruit Board (BFB) set A. 37.


Fig. 4. Scale used to score pedicel-end cracks on ‘Fuji’ apples that were stored under controlled atmosphere for three months (0- no cracks, 1 – first sign of developing cracks 2 – mild cracks, 3 – moderate cracks and 4 – severe cracks).

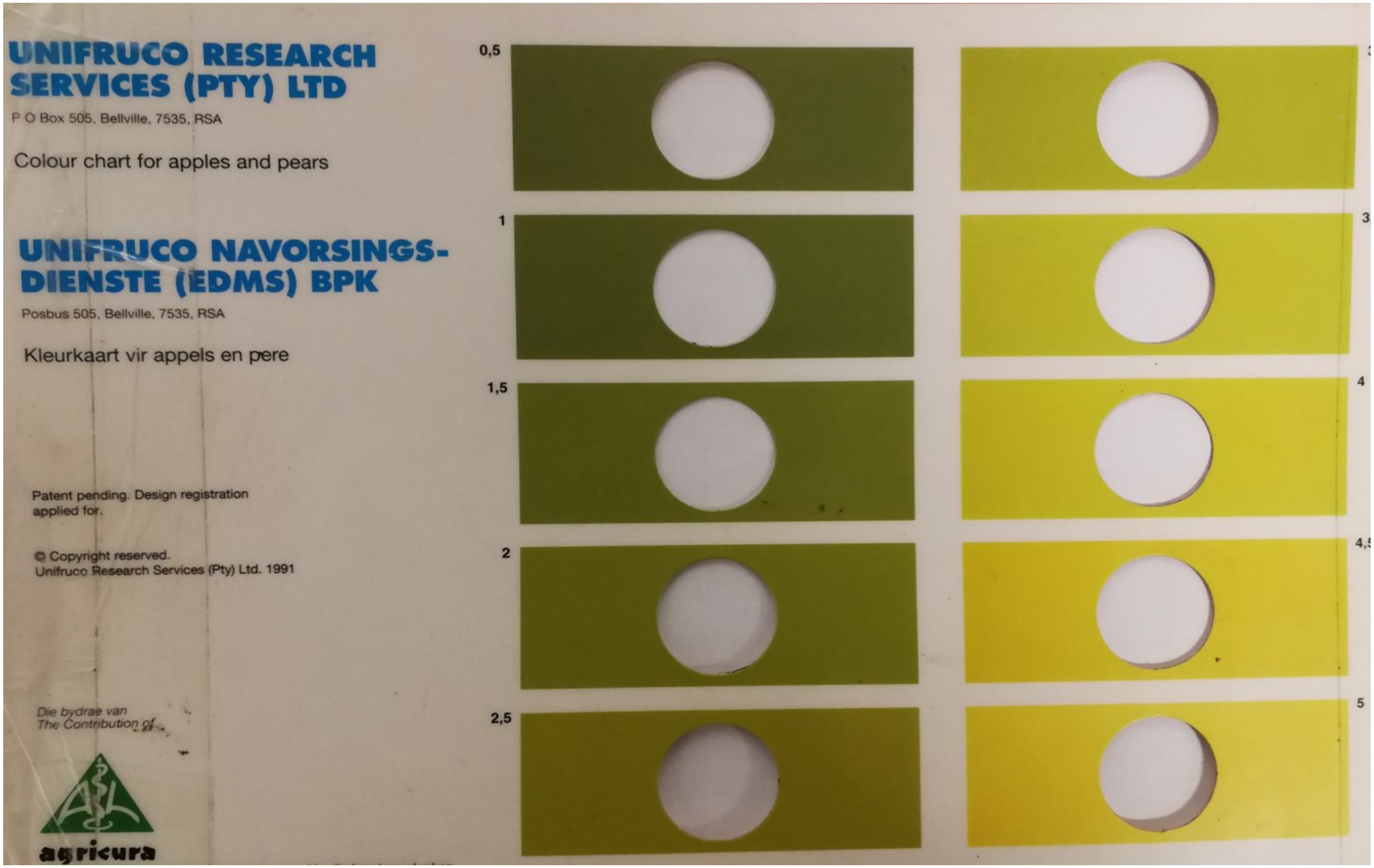


Fig. 5. Unifruco Research Services ground color chart for apples and pears.

Table 1. Treatment details for trials with gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on 'Fuji' and 'Rosy Glow' apples in the seasons of 2017/2018 and 2018/2019.

| Treatment rates* | Application times |
|---|---|
| Untreated control | |
| $GA_{4+7}$ + 6-BA at 10 mg·$L^{-1}$[a] (early) | 7, 14 and 21 d.a.f.b.** |
| $GA_{4+7}$ + 6-BA at 20 mg·$L^{-1}$[b] (early) | 7, 14 and 21 d.a.f.b.** |
| $GA_{4+7}$ + 6-BA at 40 mg·$L^{-1}$[c] (early) | 7, 14 and 21 d.a.f.b.** |
| $GA_{4+7}$ + 6-BA at 10 mg·$L^{-1}$[a] (late) | 7, 21 and 35 d.a.f.b.** |
| $GA_{4+7}$ + 6-BA at 20 mg ·$L^{-1}$[b] (late) | 7, 21 and 35 d.a.f.b.** |
| $GA_{4+7}$ + 6-BA at 40 mg·$L^{-1}$[c] (late) | 7, 21 and 35 d.a.f.b.** |

* Rates of active ingredients; ** Days after full bloom; [a] 10 mg·$L^{-1}$ $GA_{4+7}$ + 10 mg·$L^{-1}$ 6-BA; [b] 20 mg·$L^{-1}$ $GA_{4+7}$ + 20 mg·$L^{-1}$ 6-BA; [c] 40 mg·$L^{-1}$ $GA_{4+7}$ + 40 mg·$L^{-1}$ 6-BA

Table 2. Treatment details for trials with gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on 'Fuji' apples in the season of 2017/2018.

| Treatment rates* | Application times |
|---|---|
| Untreated control | |
| $GA_{4+7}$ at 10 mg·$L^{-1}$ (early) | 7, 14 and 21 d.a.f.b.** |
| $GA_{4+7}$ at 20 mg·$L^{-1}$ (early) | 7, 14 and 21 d.a.f.b.** |
| $GA_{4+7}$ at 40 mg·$L^{-1}$ (early) | 7, 14 and 21 d.a.f.b.** |
| $GA_{4+7}$ at 10 mg·$L^{-1}$ (late) | 7, 21 and 35 d.a.f.b.** |
| $GA_{4+7}$ at 20 mg·$L^{-1}$ (late) | 7, 21 and 35 d.a.f.b.** |
| $GA_{4+7}$ at 40 mg·$L^{-1}$ (late) | 7, 21 and 35 d.a.f.b.** |

* Rates of active ingredients; ** Days after full bloom

Table 3. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on fruit set per cluster on two marked branches and number of hand thinned fruitlets per tree of 'Fuji' apples at Vastrap, Witzenberg valley, South Africa (2017/2018).

| Treatment | Average fruit set per cluster on two tagged branches* | | Average number of hand thinned fruitlets per tree | |
|---|---|---|---|---|
| Untreated control | 1.36 | ab | 145.80 | a |
| $GA_{4+7}$ + 6-BA 10[a] | 1.22 | abc | 135.80 | a |
| $GA_{4+7}$ + 6-BA 20[a] | 1.18 | abc | 135.10 | a |
| $GA_{4+7}$ + 6-BA 40[a] | 0.85 | c | 70.00 | b |
| $GA_{4+7}$ + 6-BA 10[b] | 1.50 | a | 153.10 | a |
| $GA_{4+7}$ + 6-BA 20[b] | 1.08 | bc | 156.10 | a |
| $GA_{4+7}$ + 6-BA 40[b] | 1.09 | bc | 120.40 | ab |
| *Significance level* | ***0.0344*** | | ***0.0297*** | |
| *LSD 5%* | *0.37* | | *52.24* | |
| Untreated control vs. rest | *0.1617* | | *0.3862* | |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.2041* | | *0.0545* | |
| *$GA_{4+7}$ + 6-BA Linear[a]* | ***0.0420*** | | ***0.0081*** | |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.5978* | | *0.3596* | |
| *$GA_{4+7}$ + 6-BA Linear[b]* | *0.0631* | | *0.1689* | |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.0901* | | *0.5478* | |

* Number of fruits after natural fruit drop /number of flower clusters at bloom; [a] $GA_{4+7}$ + 6-BA applied: 24 Oct. 2017 + 1 and 7 Nov. 2017; [b] $GA_{4+7}$ + 6-BA applied: 24 Oct. 2017 + 7 and 23 Nov. 2017

Table 4. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on the fruit size of 'Fuji' apples at Vastrap, Witzenberg valley, South Africa (2017/2018).

| Treatment | Average fruit weight at 2018 harvest (g) | | Average fruit length at 2018 harvest (mm) | | Average fruit diameter at 2018 harvest (mm) | |
|---|---|---|---|---|---|---|
| Untreated control | 147.4 | ns | 59.7 | c | 68.9 | c |
| $GA_{4+7}$ + 6-BA 10[a] | 152.1 | | 60.4 | bc | 69.9 | bc |
| $GA_{4+7}$ + 6-BA 20[a] | 155.5 | | 60.8 | bc | 70.7 | ab |
| $GA_{4+7}$ + 6-BA 40[a] | 159.7 | | 63.1 | a | 70.9 | ab |
| $GA_{4+7}$ + 6-BA 10[b] | 154.4 | | 61.4 | b | 70.7 | ab |
| $GA_{4+7}$ + 6-BA 20[b] | 151.6 | | 61.0 | bc | 70.1 | abc |
| $GA_{4+7}$ + 6-BA 40[b] | 152.1 | | 60.4 | bc | 71.3 | a |
| *Significance level* | *0.1482* | | ***0.0053*** | | ***0.0114*** | |
| *LSD 5%* | - | | *1.64* | | *1.32* | |
| Untreated control vs. rest | ***0.0384*** | | ***0.0164*** | | ***0.0012*** | |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.2095* | | *0.2947* | | *0.5801* | |
| *$GA_{4+7}$ + 6-BA Linear[a]* | *0.0756* | | ***0.0011*** | | *0.1362* | |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.8135* | | *0.4733* | | *0.4301* | |
| *$GA_{4+7}$ + 6-BA Linear[b]* | *0.6533* | | *0.2561* | | *0.2458* | |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.5785* | | *0.9887* | | *0.1458* | |

[a] $GA_{4+7}$ + 6-BA applied: 24 Oct. 2017 + 1 and 7 Nov. 2017; [b] $GA_{4+7}$ + 6-BA applied: 24 Oct. 2017 + 7 and 23 Nov. 2017

Table 5. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on the fruit quality of 'Fuji' apples at Vastrap, Witzenberg valley, South Africa (2017/2018).

| Treatment | % Fruit with calyx-end ribbing | | Average ground color[c] of RA[d] stored fruit | | Average ground color[c] of CA[e] stored fruit | |
|---|---|---|---|---|---|---|
| Untreated control | 6.63 | c | 3.14 | b | 3.04 | c |
| $GA_{4+7}$ + 6-BA 10[a] | 11.63 | bc | 3.13 | b | 3.24 | abc |
| $GA_{4+7}$ + 6-BA 20[a] | 8.63 | c | 3.22 | ab | 3.19 | bc |
| $GA_{4+7}$ + 6-BA 40[a] | 18.74 | a | 3.40 | a | 3.43 | a |
| $GA_{4+7}$ + 6-BA 10[b] | 14.63 | ab | 3.36 | a | 3.32 | ab |
| $GA_{4+7}$ + 6-BA 20[b] | 7.00 | c | 3.16 | b | 3.05 | c |
| $GA_{4+7}$ + 6-BA 40[b] | 9.25 | bc | 3.25 | ab | 3.09 | c |
| *Significance level* | ***0.0005*** | | ***0.0264*** | | ***0.0041*** | |
| *LSD 5%* | *5.72* | | *0.19* | | *0.22* | |
| Untreated control vs. rest | ***0.0250*** | | *0.1158* | | ***0.0379*** | |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.1057* | | *0.9592* | | ***0.0340*** | |
| *$GA_{4+7}$ + 6-BA Linear[a]* | ***0.0046*** | | ***0.0049*** | | *0.0518* | |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | ***0.0371*** | | *0.9679* | | *0.2215* | |
| *$GA_{4+7}$ + 6-BA Linear[b]* | *0.1465* | | *0.4288* | | *0.0787* | |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | ***0.0242*** | | *0.0520* | | *0.0516* | |

[a] $GA_{4+7}$ + 6-BA applied: 24 Oct. 2017 + 1 and 7 Nov. 2017; [b] $GA_{4+7}$ + 6-BA applied: 24 Oct. 2017 + 7 and 23 Nov. 2017; [c] Ground color: – Indication of change in ground color from green to yellow in 0.5 intervals ( 0.5 – green to 5 – yellow); [d] RA – Regular Atmosphere storage; [e] CA – Controlled atmosphere storage

Table 6. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on yield efficiency and the return bloom of 'Fuji' apples at Vastrap, Witzenberg valley, South Africa (2017/2018).

| Treatment | Total yield per tree (kg) | | Estimated yield per hectare (ton) | Total yield Efficiency ($kg \cdot cm^{-2}$) | | Percentage return bloom on two tagged branches* | |
|---|---|---|---|---|---|---|---|
| Untreated control | 62.95 | ns | 89.93 | 0.79 | ns | 12.44 | a |
| $GA_{4+7}$ + 6-BA 10[a] | 61.20 | | 87.43 | 0.83 | | 5.23 | bc |
| $GA_{4+7}$ + 6-BA 20[a] | 67.02 | | 95.74 | 0.93 | | 4.03 | bc |
| $GA_{4+7}$ + 6-BA 40[a] | 61.59 | | 87.99 | 0.77 | | 3.53 | bc |
| $GA_{4+7}$ + 6-BA 10[b] | 62.63 | | 89.47 | 0.85 | | 6.52 | b |
| $GA_{4+7}$ + 6-BA 20[b] | 69.06 | | 98.66 | 0.87 | | 4.85 | bc |
| $GA_{4+7}$ + 6-BA 40[b] | 76.13 | | 108.76 | 0.99 | | 2.29 | c |
| *Significance level* | *0.2021* | | - | *0.1858* | | ***0.0001*** | |
| *LSD 5%* | - | | - | - | | *3.97* | |
| Untreated control vs. rest | *0.4924* | | - | *0.2350* | | ***<.0001*** | |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.1041* | | - | *0.2472* | | *0.7977* | |
| *$GA_{4+7}$ + 6-BA Linear[a]* | *0.8930* | | - | *0.3340* | | *0.4252* | |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.3097* | | - | *0.1373* | | *0.7177* | |
| *$GA_{4+7}$ + 6-BA Linear[b]* | ***0.0388*** | | - | *0.0901* | | ***0.0361*** | |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.7293* | | - | *0.6819* | | *0.8814* | |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds); [a] $GA_{4+7}$ + 6-BA applied: 24 Oct. 2017 + 1 and 7 Nov. 2017; [b] $GA_{4+7}$ + 6-BA applied: 24 Oct. 2017 + 7 and 23 Nov. 2017

Table 7. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on fruit set per cluster on two marked branches and number of hand thinned fruitlets per tree of 'Fuji' apples at Vastrap, Witzenberg valley, South Africa (2017/2018).

| Treatment | Average fruit set per cluster on two tagged branches* | Average number of hand thinned fruitlets per tree |
|---|---|---|
| Untreated control | 1.26 ns | 168.80 ab |
| $GA_{4+7}$ 10[a] | 1.25 | 159.80 abc |
| $GA_{4+7}$ 20[a] | 1.12 | 119.30 cd |
| $GA_{4+7}$ 40[a] | 1.16 | 115.30 d |
| $GA_{4+7}$ 10[b] | 1.17 | 189.60 a |
| $GA_{4+7}$ 20[b] | 1.04 | 149.70 abcd |
| $GA_{4+7}$ 40[b] | 1.06 | 132.30 bcd |
| *Significance level* | *0.3602* | ***0.0057*** |
| *LSD 5%* | - | *41.43* |
| Untreated control vs. rest | *0.1541* | *0.1269* |
| *$GA_{4+7}{}^a$ vs. $GA_{4+7}{}^b$* | *0.1906* | ***0.0355*** |
| *$GA_{4+7}$ Linear[a]* | *0.5901* | *0.0599* |
| *$GA_{4+7}$ Quadratic[a]* | *0.3167* | *0.1647* |
| *$GA_{4+7}$ Linear[b]* | *0.4186* | ***0.0119*** |
| *$GA_{4+7}$ Quadratic[b]* | *0.3401* | *0.2587* |

* Number of fruits after natural fruit drop /number of flower clusters at bloom; [a] $GA_{4+7}$ applied: 24 Oct. 2017 + 1 and 7 Nov. 2017; [b] $GA_{4+7}$ applied: 24 Oct. 2017 + 7 and 23 Nov. 2017

Table 8. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the fruit size of 'Fuji' apples at Vastrap, Witzenberg valley, South Africa (2017/2018).

| Treatment | Average fruit weight at 2018 harvest (g) | Average fruit length at 2018 harvest (mm) | Average fruit diameter at 2018 harvest (mm) |
|---|---|---|---|
| Untreated control | 153.5 ns | 60.9 b | 72.0 ab |
| $GA_{4+7}$ 10[1] | 162.5 | 63.7 a | 73.1 a |
| $GA_{4+7}$ 20[1] | 153.9 | 62.0 ab | 72.3 ab |
| $GA_{4+7}$ 40[1] | 162.7 | 63.8 a | 72.3 ab |
| $GA_{4+7}$ 10[2] | 155.9 | 62.3 ab | 70.9 bc |
| $GA_{4+7}$ 20[2] | 157.0 | 62.2 ab | 71.4 ab |
| $GA_{4+7}$ 40[2] | 145.9 | 60.6 b | 69.3 c |
| *Significance level* | *0.0993* | ***0.0303*** | ***0.0022*** |
| *LSD 5%* | - | *2.16* | *1.76* |
| Untreated control vs. rest | *0.5336* | *0.0714* | *0.5274* |
| *$GA_{4+7}{}^a$ vs. $GA_{4+7}{}^b$* | *0.0536* | ***0.0248*** | ***0.0002*** |
| *$GA_{4+7}$ Linear[a]* | *0.7264* | *0.6135* | *0.3980* |
| *$GA_{4+7}$ Quadratic[a]* | *0.1042* | *0.0797* | *0.4649* |
| *$GA_{4+7}$ Linear[b]* | *0.0680* | *0.0945* | ***0.0374*** |
| *$GA_{4+7}$ Quadratic[b]* | *0.3963* | *0.6366* | *0.1651* |

[a] $GA_{4+7}$ applied: 24 Oct. 2017 + 1 and 7 Nov. 2017; [b] $GA_{4+7}$ applied: 24 Oct. 2017 + 7 and 23 Nov. 2017

Table 9. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on the fruit quality of 'Fuji' apples at Vastrap, Witzenberg valley, South Africa (2017/2018).

| Treatment | % Fruit with calyx-end ribbing | Average ground color[c] of RA[d] stored fruit | Average ground color[c] of CA[e] stored fruit |
|---|---|---|---|
| Untreated control | 9.00 c | 3.24 c | 3.50 ns |
| $GA_{4+7}$ 10[a] | 19.25 ab | 3.44 bc | 3.46 |
| $GA_{4+7}$ 20[a] | 17.63 ab | 3.80 a | 3.26 |
| $GA_{4+7}$ 40[a] | 19.88 a | 3.70 ab | 3.25 |
| $GA_{4+7}$ 10[b] | 14.13 bc | 3.69 ab | 3.06 |
| $GA_{4+7}$ 20[b] | 14.75 ab | 3.43 bc | 3.19 |
| $GA_{4+7}$ 40[b] | 14.88 ab | 3.31 c | 3.15 |
| *Significance level* | ***0.0064*** | ***0.0014*** | *0.1415* |
| *LSD 5%* | *5.71* | *0.30* | - |
| Untreated control vs. rest | ***0.0008*** | ***0.0064*** | *0.0501* |
| *$GA_{4+7}$[a] vs. $GA_{4+7}$[b]* | ***0.0109*** | *0.0506* | *0.0634* |
| *$GA_{4+7}$ Linear[a]* | *0.7172* | *0.1805* | *0.2944* |
| *$GA_{4+7}$ Quadratic[a]* | *0.4684* | ***0.0395*** | *0.3752* |
| *$GA_{4+7}$ Linear[b]* | *0.8116* | ***0.0165*** | *0.7059* |
| *$GA_{4+7}$ Quadratic[b]* | *0.8818* | *0.2939* | *0.4995* |

[a] $GA_{4+7}$ applied: 24 Oct. 2017 + 1 and 7 Nov. 2017; [b] $GA_{4+7}$ applied: 24 Oct. 2017 + 7 and 23 Nov. 2017; [c] Ground color: – Indication of change in ground color from green to yellow in 0.5 intervals ( 0.5 – green to 5 – yellow); [d] RA – Regular Atmosphere storage; [e] CA – Controlled atmosphere storage

Table 10. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) on yield efficiency and the return bloom of 'Fuji' apples at Vastrap, Witzenberg valley, South Africa (2017/2018).

| Treatment | Total yield per tree (kg) | Estimated yield per hectare (ton) | Total yield Efficiency ($kg \cdot cm^{-2}$) | Percentage return bloom on two tagged branches* |
|---|---|---|---|---|
| Untreated control | 71.33 ns | 101.90 | 0.85 ns | 9.24 a |
| $GA_{4+7}$ 10[a] | 65.91 | 94.16 | 0.79 | 4.82 b |
| $GA_{4+7}$ 20[a] | 63.49 | 90.70 | 0.80 | 1.70 c |
| $GA_{4+7}$ 40[a] | 70.60 | 100.86 | 0.81 | 1.55 c |
| $GA_{4+7}$ 10[b] | 70.79 | 101.13 | 0.88 | 2.27 bc |
| $GA_{4+7}$ 20[b] | 67.45 | 96.36 | 0.87 | 2.27 bc |
| $GA_{4+7}$ 40[b] | 63.65 | 90.93 | 0.86 | 1.11 c |
| *Significance level* | *0.6320* | - | *0.7276* | ***<.0001*** |
| *LSD 5%* | - | - | - | *2.70* |
| Untreated control vs. rest | *0.3149* | - | *0.7910* | ***<.0001*** |
| *$GA_{4+7}$[a] vs. $GA_{4+7}$[b]* | *0.8467* | - | *0.0726* | *0.3041* |
| *$GA_{4+7}$ Linear[a]* | *0.3189* | - | *0.7724* | ***0.0368*** |
| *$GA_{4+7}$ Quadratic[a]* | *0.4250* | - | *0.8706* | *0.0922* |
| *$GA_{4+7}$ Linear[b]* | *0.2137* | - | *0.8201* | *0.3543* |
| *$GA_{4+7}$ Quadratic[b]* | *0.8478* | - | *0.8801* | *0.7436* |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds); [a] $GA_{4+7}$ applied: 24 Oct. 2017 + 1 and 7 Nov. 2017; [b] $GA_{4+7}$ applied: 24 Oct. 2017 + 7 and 23 Nov. 2017

Table 11. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on fruit set per cluster on two marked branches and number of hand thinned fruitlets per tree of 'Fuji' apples at Welgemeen, Witzenberg valley, South Africa (2018/2019).

| Treatment | Average fruit set per cluster on two tagged branches* | Average number of hand thinned fruitlets per tree |
|---|---|---|
| Untreated control | 0.78 ns | 353.4 ns |
| $GA_{4+7}$ + 6-BA 10[a] | 0.98 | 286.8 |
| $GA_{4+7}$ + 6-BA 20[a] | 0.99 | 312.3 |
| $GA_{4+7}$ + 6-BA 40[a] | 0.83 | 345.0 |
| $GA_{4+7}$ + 6-BA 10[b] | 1.04 | 298.4 |
| $GA_{4+7}$ + 6-BA 20[b] | 0.83 | 274.5 |
| $GA_{4+7}$ + 6-BA 40[b] | 0.78 | 286.3 |
| *Significance level* | *0.2391* | *0.8852* |
| *LSD 5%* | - | - |
| Untreated control vs. rest | *0.2171* | *0.3238* |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.4912* | *0.4836* |
| *$GA_{4+7}$ + 6-BA Linear[a]* | *0.2163* | *0.4081* |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.6019* | *0.9211* |
| *$GA_{4+7}$ + 6-BA Linear[b]* | *0.0750* | *0.9089* |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.2971* | *0.7471* |

* Number of fruits after natural fruit drop /number of flower clusters at bloom; [a] $GA_{4+7}$ + 6-BA applied: 23 and 31 Oct. 2018 + 6 Nov. 2018; [b] $GA_{4+7}$ + 6-BA applied: 23 Oct. 2018 + 6 and 21 Nov. 2018

Table 12. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on the fruit size of 'Fuji' apples at Welgemeen, Witzenberg valley, South Africa (2018/2019).

| Treatment | Average fruit weight at 2019 harvest (g) | Average fruit length at 2019 harvest (mm) | Average fruit diameter at 2019 harvest (mm) |
|---|---|---|---|
| Untreated control | 203.01 ns | 63.27 ab | 79.40 a |
| $GA_{4+7}$ + 6-BA 10[a] | 198.26 | 64.36 a | 78.80 ab |
| $GA_{4+7}$ + 6-BA 20[a] | 198.01 | 64.49 a | 78.62 ab |
| $GA_{4+7}$ + 6-BA 40[a] | 205.69 | 63.10 ab | 79.08 ab |
| $GA_{4+7}$ + 6-BA 10[b] | 196.53 | 61.28 bc | 76.54 bc |
| $GA_{4+7}$ + 6-BA 20[b] | 182.03 | 60.14 c | 74.33 c |
| $GA_{4+7}$ + 6-BA 40[b] | 188.73 | 61.19 bc | 75.25 c |
| *Significance level* | *0.2047* | ***0.0122*** | ***0.0006*** |
| *LSD 5%* | - | *2.75* | *2.66* |
| Untreated control vs. rest | *0.2680* | *0.4214* | ***0.0275*** |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | ***0.0402*** | ***0.0002*** | ***<.0001*** |
| *$GA_{4+7}$ + 6-BA Linear[a]* | *0.3947* | *0.3108* | *0.7932* |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.7464* | *0.6534* | *0.8152* |
| *$GA_{4+7}$ + 6-BA Linear[b]* | *0.5764* | *0.9140* | *0.4897* |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.1621* | *0.3612* | *0.1351* |

[a] $GA_{4+7}$ + 6-BA applied: 23 and 31 Oct. 2018 + 6 Nov. 2018; [b] $GA_{4+7}$ + 6-BA applied: 23 Oct. 2018 + 6 and 21 Nov. 2018

Table 13. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on the fruit quality of 'Fuji' apples at Welgemeen, Witzenberg valley, South Africa (2018/2019).

| Treatment | % CA stored fruit with pedicel-end cracks | Average pedicel-end crack score[c] on CA stored fruit | % CA stored fruit with a pedicel-end crack score[e] >1 | % Fruit with calyx-end ribbing | Average ground color[d] of RA[e] stored fruit | Average ground color[d] of CA[f] stored fruit |
|---|---|---|---|---|---|---|
| Untreated control | 16.07 ns | 0.26 ns | 4.79 a | 1.45 c | 3.38 ns | 3.49 b |
| $GA_{4+7}$ + 6-BA 10[a] | 14.12 | 0.17 | 2.31 b | 1.05 c | 3.40 | 3.51 b |
| $GA_{4+7}$ + 6-BA 20[a] | 14.68 | 0.17 | 1.64 b | 1.87 c | 3.53 | 3.72 a |
| $GA_{4+7}$ + 6-BA 40[a] | 13.44 | 0.16 | 1.96 b | 6.61 bc | 3.49 | 3.37 b |
| $GA_{4+7}$ + 6-BA 10[b] | 10.48 | 0.12 | 0.78 b | 12.92 ab | 3.68 | 3.46 b |
| $GA_{4+7}$ + 6-BA 20[b] | 12.58 | 0.14 | 1.08 b | 13.62 ab | 3.52 | 3.45 b |
| $GA_{4+7}$ + 6-BA 40[b] | 17.47 | 0.19 | 1.67 b | 14.53 a | 3.59 | 3.52 b |
| *Significance level* | *0.5532* | *0.2026* | ***0.0429*** | ***0.0002*** | *0.0507* | ***0.0057*** |
| *LSD 5%* | - | - | *2.44* | *7.42* | - | *0.16* |
| Untreated control vs. rest | *0.4221* | ***0.0148*** | ***0.0011*** | ***0.0167*** | ***0.0412*** | *0.7592* |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.8122* | *0.6843* | *0.2638* | ***<.0001*** | ***0.0357*** | *0.2415* |
| *$GA_{4+7}$ + 6-BA Linear[a]* | *0.8124* | *0.8071* | *0.8433* | *0.1175* | *0.4615* | ***0.0222*** |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.8080* | *0.9752* | *0.6059* | *0.7531* | *0.2556* | ***0.0007*** |
| *$GA_{4+7}$ + 6-BA Linear[b]* | ***0.0470*** | *0.1348* | *0.4575* | *0.6674* | *0.5065* | *0.4284* |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.9256* | *0.9395* | *0.9962* | *0.9595* | *0.1393* | *0.6037* |

[a] $GA_{4+7}$ + 6-BA applied: 23 and 31 Oct. 2018 + 6 Nov. 2018
[b] $GA_{4+7}$ + 6-BA applied: 23 Oct. 2018 + 6 and 21 Nov. 2018
[c] Crack score = 0 – no cracks; 1 – first sign of developing cracks; 2 – mild cracks; 3 – moderate cracks; 4 – severe cracks
[d] Ground color: – Indication of change in ground color from green to yellow in 0.5 intervals (0.5 – green to 5 – yellow)
[e] RA – Regular Atmosphere storage
[f] CA – Controlled atmosphere storage

Table 14. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on yield efficiency and the return bloom of 'Fuji' apples at Welgemeen, Witzenberg valley, South Africa (2018/2019).

| Treatment | Total yield per tree (kg) | Estimated yield per hectare (ton) | Total yield Efficiency ($kg\cdot cm^{-2}$) | Percentage return bloom on two tagged branches* |
|---|---|---|---|---|
| Untreated control | 64.29 ns | 80.36 | 0.36 ns | 34.50 ns |
| $GA_{4+7}$ + 6-BA 10[a] | 66.95 | 83.69 | 0.44 | 33.50 |
| $GA_{4+7}$ + 6-BA 20[a] | 67.60 | 84.50 | 0.43 | 32.26 |
| $GA_{4+7}$ + 6-BA 40[a] | 72.34 | 90.43 | 0.48 | 28.22 |
| $GA_{4+7}$ + 6-BA 10[b] | 52.68 | 65.85 | 0.40 | 36.92 |
| $GA_{4+7}$ + 6-BA 20[b] | 66.54 | 83.18 | 0.51 | 34.67 |
| $GA_{4+7}$ + 6-BA 40[b] | 52.35 | 65.44 | 0.42 | 28.99 |
| *Significance level* | *0.1324* | - | *0.5905* | *0.2344* |
| *LSD 5%* | - | - | - | - |
| Untreated control vs. rest | *0.8497* | - | *0.1758* | *0.4742* |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | ***0.0174*** | - | *0.8953* | *0.3179* |
| *$GA_{4+7}$ + 6-BA Linear[a]* | *0.4926* | - | *0.6373* | *0.1520* |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.8763* | - | *0.6976* | *0.8752* |
| *$GA_{4+7}$ + 6-BA Linear[b]* | *0.6861* | - | *0.9828* | ***0.0351*** |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.0619* | - | *0.1277* | *0.9067* |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds); [a] $GA_{4+7}$ + 6-BA applied: 23 and 31 Oct. 2018 + 6 Nov. 2018; [b] $GA_{4+7}$ + 6-BA applied: 23 Oct. 2018 + 6 and 21 Nov. 2018

Table 15. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on fruit set per cluster on two marked branches and number of hand thinned fruitlets per tree of 'Rosy Glow' apples at Welgemeen, Witzenberg valley, South Africa (2018/2019).

| Treatment | Average fruit set per cluster on two tagged branches* | Average number of hand thinned fruitlets per tree |
|---|---|---|
| Untreated control | 0.47 ab | 240.4 a |
| $GA_{4+7}$ + 6-BA 10[a] | 0.39 bc | 143.6 b |
| $GA_{4+7}$ + 6-BA 20[a] | 0.47 ab | 135.2 b |
| $GA_{4+7}$ + 6-BA 40[a] | 0.36 bc | 101.5 b |
| $GA_{4+7}$ + 6-BA 10[b] | 0.51 a | 127.8 b |
| $GA_{4+7}$ + 6-BA 20[b] | 0.40 abc | 132.5 b |
| $GA_{4+7}$ + 6-BA 40[b] | 0.34 c | 130.7 b |
| *Significance level* | ***0.0374*** | ***0.0006*** |
| *LSD 5%* | *0.12* | *57.77* |
| Untreated control vs. rest | *0.2021* | ***<.0001*** |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.7359* | *0.8311* |
| *$GA_{4+7}$ + 6-BA Linear[a]* | *0.3917* | *0.1318* |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.0737* | *0.8254* |
| *$GA_{4+7}$ + 6-BA Linear[b]* | ***0.0071*** | *0.9411* |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.3448* | *0.8838* |

* Number of fruits after natural fruit drop /number of flower clusters at bloom; [a] $GA_{4+7}$ + 6-BA applied: 23 and 31 Oct. 2018 + 6 Nov. 2018; [b] $GA_{4+7}$ + 6-BA applied: 23 Oct. 2018 + 6 and 21 Nov. 2018

Table 16. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on the fruit size of 'Rosy Glow' apples at Welgemeen, Witzenberg valley, South Africa (2018/2019).

| Treatment | Average fruit weight at 2019 harvest (g) | | Average fruit length at 2019 harvest (mm) | | Average fruit diameter at 2019 harvest (mm) | |
|---|---|---|---|---|---|---|
| Untreated control | 152.47 | c | 65.28 | d | 70.79 | c |
| $GA_{4+7}$ + 6-BA 10[a] | 160.37 | bc | 66.79 | bcd | 72.88 | ab |
| $GA_{4+7}$ + 6-BA 20[a] | 164.27 | ab | 67.04 | abc | 72.91 | ab |
| $GA_{4+7}$ + 6-BA 40[a] | 170.36 | a | 68.38 | a | 73.62 | ab |
| $GA_{4+7}$ + 6-BA 10[b] | 159.92 | bc | 66.29 | cd | 72.35 | b |
| $GA_{4+7}$ + 6-BA 20[b] | 168.00 | ab | 67.66 | abc | 73.43 | ab |
| $GA_{4+7}$ + 6-BA 40[b] | 167.25 | ab | 67.84 | ab | 73.82 | a |
| *Significance level* | ***0.0061*** | | ***0.0038*** | | ***0.0018*** | |
| *LSD 5%* | *9.39* | | *1.54* | | *1.44* | |
| Untreated control vs. rest | ***0.0009*** | | ***0.0010*** | | ***<.0001*** | |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.9842* | | *0.7529* | | *0.8786* | |
| *$GA_{4+7}$ + 6-BA Linear[a]* | ***0.0366*** | | ***0.0336*** | | *0.2685* | |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.8912* | | *0.6822* | | *0.7393* | |
| *$GA_{4+7}$ + 6-BA Linear[b]* | *0.1889* | | *0.0751* | | *0.0633* | |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.1781* | | *0.2124* | | *0.3575* | |

[a] $GA_{4+7}$ + 6-BA applied: 23 and 31 Oct. 2018 + 6 Nov. 2018; [b] $GA_{4+7}$ + 6-BA applied: 23 Oct. 2018 + 6 and 21 Nov. 2018

Table 17. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on the fruit quality of 'Rosy Glow' apples at Welgemeen, Witzenberg valley, South Africa (2018/2019).

| Treatment | Percentage fruit with calyx-end ribbing | | Average ground color[c] of RA[d] stored fruit | | Average ground color[c] of CA[e] stored fruit | |
|---|---|---|---|---|---|---|
| Untreated control | 0.13 | ns | 3.67 | ns | 3.78 | bc |
| $GA_{4+7}$ + 6-BA 10[a] | 0.00 | | 3.77 | | 3.73 | c |
| $GA_{4+7}$ + 6-BA 20[a] | 0.74 | | 3.64 | | 3.69 | c |
| $GA_{4+7}$ + 6-BA 40[a] | 1.01 | | 3.90 | | 3.86 | ab |
| $GA_{4+7}$ + 6-BA 10[b] | 0.43 | | 3.88 | | 3.92 | a |
| $GA_{4+7}$ + 6-BA 20[b] | 0.00 | | 3.73 | | 3.87 | ab |
| $GA_{4+7}$ + 6-BA 40[b] | 0.28 | | 3.85 | | 3.80 | abc |
| *Significance level* | *0.2109* | | *0.2519* | | ***0.0032*** | |
| *LSD 5%* | - | | - | | *0.12* | |
| Untreated control vs. rest | *0.4127* | | *0.1959* | | *0.5199* | |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.1879* | | *0.4795* | | ***0.0049*** | |
| *$GA_{4+7}$ + 6-BA Linear[a]* | ***0.0425*** | | *0.1730* | | ***0.0112*** | |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.3123* | | *0.1284* | | *0.1061* | |
| *$GA_{4+7}$ + 6-BA Linear[b]* | *0.8899* | | *0.9884* | | ***0.0480*** | |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.3474* | | *0.2138* | | *0.9418* | |

[a] $GA_{4+7}$ + 6-BA applied: 23 and 31 Oct. 2018 + 6 Nov. 2018; [b] $GA_{4+7}$ + 6-BA applied: 23 Oct. 2018 + 6 and 21 Nov. 2018; [c] Ground color: – Indication of change in ground color from green to yellow in 0.5 intervals ( 0.5 – green to 5 – yellow); [d] RA – Regular Atmosphere storage; [e] CA – Controlled atmosphere storage;

Table 18. Effect of gibberellin $A_4$+$A_7$ ($GA_{4+7}$) + 6-benzyladenine (6-BA) on yield efficiency and the return bloom of 'Rosy Glow' apples at Welgemeen, Witzenberg valley, South Africa (2018/2019).

| Treatment | Total yield per tree (kg) | Estimated yield per hectare (ton) | Total yield Efficiency ($kg \cdot cm^{-2}$) | Percentage return bloom on two tagged branches* |
|---|---|---|---|---|
| Untreated control | 68.76 ns | 76.40 | 0.72 ns | 52.26 ns |
| $GA_{4+7}$ + 6-BA 10[a] | 56.54 | 62.82 | 0.70 | 48.24 |
| $GA_{4+7}$ + 6-BA 20[a] | 71.17 | 79.08 | 0.86 | 48.96 |
| $GA_{4+7}$ + 6-BA 40[a] | 72.74 | 80.82 | 0.83 | 45.42 |
| $GA_{4+7}$ + 6-BA 10[b] | 65.17 | 72.41 | 0.78 | 47.21 |
| $GA_{4+7}$ + 6-BA 20[b] | 64.92 | 72.13 | 0.81 | 43.12 |
| $GA_{4+7}$ + 6-BA 40[b] | 64.83 | 72.03 | 0.70 | 43.61 |
| *Significance level* | *0.1779* | - | *0.3942* | *0.2248* |
| *LSD 5%* | - | - | - | - |
| Untreated control vs. rest | *0.5387* | - | *0.3894* | ***0.0393*** |
| $GA_{4+7}$ + 6-BA[a] vs. $GA_{4+7}$ + 6-BA[b] | *0.6001* | - | *0.5287* | *0.1957* |
| *$GA_{4+7}$ + 6-BA Linear[a]* | ***0.0205*** | - | *0.2325* | *0.4010* |
| *$GA_{4+7}$ + 6-BA Quadratic[a]* | *0.0901* | - | *0.1355* | *0.6246* |
| *$GA_{4+7}$ + 6-BA Linear[b]* | *0.9588* | - | *0.3079* | *0.4299* |
| *$GA_{4+7}$ + 6-BA Quadratic[b]* | *0.9793* | - | *0.5161* | *0.3945* |

* Return bloom = (Reproductive buds x 100/ Reproductive buds + Vegetative buds); [a] $GA_{4+7}$ + 6-BA applied: 23 and 31 Oct. 2018 + 6 Nov. 2018; [b] $GA_{4+7}$ + 6-BA applied: 23 Oct. 2018 + 6 and 21 Nov. 2018

# GENERAL DISCUSSION AND CONCLUSIONS

The plant growth regulators (PGRs), $GA_{4+7}$ and $GA_{4+7}$ + 6-BA were evaluated to improve the pedicel length of the fruit of apple cultivars Nicoter, Fuji and Cripps' Pink in the Elgin-Grabouw-Vyeboom-Villiersdorp (EGVV) region as these pedicels tend to be short, stubby and rigid, thus causing losses pre- and post-harvest.

Lower rates of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA (5, 10 and 20 $mg \cdot L^{-1}$) evaluated in the first season had little or no effect on the pedicel length of 'Nicoter' and 'Cripps' Pink' apples, while having some effect on the pedicel diameter and weight. All treatments were applied at pink bud stage, seven and 14 days after pink bud and a large portion of the treated trees were already at full bloom between the last two applications (personal observation). As pedicel elongation ends at full bloom (Prive et al., 1988), the relatively small effect on pedicel length could thus be due to the later applications missing the target phenological stage. Expansion of the pedicel diameter only concludes three to four weeks after full bloom (Prive et al., 1988), thus explaining the stronger response on diameter and weight. On 'Fuji' apples, however, the lower rates improved the pedicel length, with 20 $mg \cdot L^{-1}$ of both PGR treatments and 10 $mg \cdot L^{-1}$ $GA_{4+7}$ + 6-BA having the longest pedicels. These promising results in the case of 'Fuji' were achieved as we managed to finish the applications prior to full bloom (personal observation). It is interesting to note that although $GA_{4+7}$ + 6-BA (Promalin®) is a registered thinning agent in South Africa for 'Golden Delicious', 'Granny Smith' and 'Royal Gala' apples at the eight to 10 mm fruitlet diameter stage (14 d.a.f.b.), the pre-bloom applications of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA also thinned 'Nicoter' and 'Cripps' Pink' flowers at rates as low as 10 $mg \cdot L^{-1}$. No negative side-effects were found with the pre-bloom applications, except for 20 $mg \cdot L^{-1}$ $GA_{4+7}$ + 6-BA over-thinning 'Cripps' Pink' and resulting in a lower yield and yield efficiency per tree. It could thus be worthwhile to evaluate $GA_{4+7}$ and $GA_{4+7}$ + 6-BA as pre-bloom thinners of apples as the earlier thinning would possibly result in larger fruit.

In the second season, earlier application (from tight cluster onwards) at higher $GA_{4+7}$ rates had a more pronounced effect on the pedicel dimensions. As the EGVV area experiences unsynchronized bud break and therefore varying phenological stages during the bloom period (North, 1995; Sagredo, 2008), the earlier applications ensured optimal coverage of flowers at responsive phenological stages prior to full bloom. In addition, multiple applications of $GA_{4+7}$ resulted in longer pedicels than a single application, due to covering a higher percentage of flowers before full bloom and covering some flowers more than once during this period. Although the two $GA_{4+7}$ applications at 200 $mg \cdot L^{-1}$ on 'Cripps' Pink' and 100 and 200 $mg \cdot L^{-}$

[1] on 'Nicoter' resulted in the longest pedicels, these are not the recommended treatments due to the thinning effect that was reflected in the reduced yield per tree. Even though we observed a linear increase in 'Nicoter' fruit size with double $GA_{4+7}$ rate with 200 mg·L$^{-1}$ resulting in bigger fruit than the control, it did not compensate for the reduction in yield. Furthermore, the return bloom of 'Cripps' Pink' apples also decreased with increasing double $GA_{4+7}$ rate with 200 mg·L$^{-1}$ significantly lower than the control. Fortunately, double $GA_{4+7}$ application at 20 and 50 mg·L$^{-1}$ also increased the pedicel length of 'Cripps' Pink' and 'Nicoter', respectively. As no negative side-effects were found with these treatments on fruit set, hand thinning requirement, fruit size, yield and return bloom, these are the recommended treatments for pedicel elongation on 'Cripps' Pink' and 'Nicoter' apples. On 'Fuji', $GA_{4+7}$ at 200 mg·L$^{-1}$, applied twice, and 10 mg·L$^{-1}$, applied four times, resulted in the longest pedicels and neither of them affected the fruit set, hand thinning requirement, yield, yield efficiency and return boom. The four 10 mg·L$^{-1}$ $GA_{4+7}$ applications is thus the recommended treatment for pedicel elongation on 'Fuji' apples as it caused more pedicels to be in the average length range compared the higher rates (Paper 1), while the increased tractor hours and labor cost with this treatment, is possibly compensated for by the cost of the significantly lower rate of the PGR.

Neither the flower position in the inflorescence, nor the bearing shoot type substantially contributed to the variable pedicel lengths on apple trees. Results on pedicel lengths were not consistent between the flowers and fruit of 'Nicoter' and 'Fuji'. The K position in clusters on long shoots of 'Nicoter' and the K and L position in clusters on long shoots of 'Cripps' Pink' had significantly longer pedicels. However, the number of bearing positions on long shoots will not be enough for an economical yield. Further research is thus needed to identify the cause of intra plant variation in pedicel lengths.

Apple pedicel length is a greater problem in the EGVV region, with its mild late autumns, warm winters and early springs compared to the colder Ceres region. As indicated by our study, GAs and 6-BA play an active role in pedicel elongation and it would be interesting to see what effect the temperature differences between Ceres and EGVV have on endogenous hormone levels during flower differentiation and thus on pedicel length. Apples of the Ceres region also tend to differ in shape (longer with increased ribbing) compared to the apples of the EGVV region and this could possibly further point at endogenous hormonal differences in spring. Trees in both the EGVV and Ceres regions are sprayed with rest breaking chemicals at bud swell, so the actual chemical application cannot be the reason for shorter pedicels in the EGVV, although rates used in EGVV are sometimes higher. It may, however, be that the period after rest breaking application is warmer in the EGVV, thus resulting in faster development until full bloom, thus reducing the time for pedicel development. Higher spring temperatures may also induce lower endogenous GA levels thus resulting in shorter pedicels. Furthermore, the interaction between pedicel growth and prohexadione-calcium should be investigated. Prohexadione-calcium (Regalis®), a GA synthesis-inhibitor (Unrath, 1999), is often applied at the pink bud stage to control vegetative growth and can possibly reduce apple pedicel length, as was found following application of the growth retardant, paclobutrazol, on 'Spartan' apples (Prive et al., 1989).

Cracking on 'Fuji' and 'Rosy Glow' apples has become a problem in the Ceres region during the past few seasons. $GA_{4+7}$, on 'Fuji', and $GA_{4+7}$ + 6-BA on 'Fuji' and 'Rosy Glow' were applied at an early and later period during the cell division phase of fruit growth to reduce the cracking incidence. Unfortunately, no pedicel-end cracks were found at harvest on 'Fuji' in both seasons, nor calyx-end cracks in 'Rosy Glow' apples during the only season investigated. This phenomenon can probably be attributed to firstly the weather. The Western Cape suffered an extreme drought during 2016 and 2017, but water resources were replenished by the time our trials started, enabling growers to irrigate optimally, and no extreme weather conditions were present, thus explaining a possible reason for the absence of cracks. 'Fuji' apples did, however, develop some small, concentric pedicel-end cracks after three months CA storage during the 2018/2019 season, similar to what Knoche and Grimm (2008) found on 'Golden Delicious'. Although very little cracking (10-17.5%) was present after CA storage, $GA_{4+7}$ + 6-BA generally reduced the severity of cracking and the percentage fruit with a crack score higher than one, thus indicating that $GA_{4+7}$ + 6-BA, applied during the cell division period, could possibly be a useful remedy if inductive conditions were to occur. In the first season, both the early 20 and 40 $mg \cdot L^{-1}$ $GA_{4+7}$ application had a thinning effect on 'Fuji', but the yield and yield efficiency were not affected. $GA_{4+7}$ + 6-BA at 40 $mg \cdot L^{-1}$ (applied at seven, 14 and 21 d.a.f.b.) thinned 'Fuji' fruitlets during the one season, while all the rates applied both early and late reduced the hand thinning requirement of 'Rosy Glow' apples. The thinning effect was to be expected as we applied $GA_{4+7}$ + 6-BA (Promalin®) at 14 d.a.f.b., i.e. the second application stage in the registration of the thinning agent. The thinning of $GA_{4+7}$ + 6-BA can be seen as positive as fruit size of 'Fuji' and 'Rosy Glow' increased, while neither the yield, nor yield efficiency per tree decreased in any of the trials. The return bloom of the 'Fuji' apples was reduced in the first season by all the $GA_{4+7}$ + 6-BA applications.

## Conclusion

Gibberellins $A_{4+7}$ successfully elongated pedicels of 'Nicoter', 'Fuji' and 'Cripps' Pink' apples when applied before full bloom. Due to unsynchronized flower phenological stages in the EGVV region, $GA_{4+7}$ needed to be applied multiple times from tight cluster to full bloom to optimize the number of clusters covered during the sensitive stage of development. The variability in pedicel dimensions of flowers and the subsequent fruit of the three cultivars was high and the cause of this variation is still unclear as neither the flower position in the inflorescence, nor the type of shoot bearing the inflorescence had a strong effect on pedicel dimensions. As a very low level of cracking was present after CA storage in 'Fuji' in one season, very little can be said regarding the efficacy of the treatments. Higher rates of $GA_{4+7}$ and $GA_{4+7}$ + 6-BA should, however, be used with caution to control cracking as the fruit set and return bloom of 'Fuji' were reduced by both, while $GA_{4+7}$ + 6-BA decreased the set of 'Rosy Glow' apples.

## Literature Cited


Knoche, M. and E. Grimm. 2008. Surface moisture induces microcracks in the cuticle of 'Golden Delicious' apple. HortSci. 43:1929–1931.

North, M.S. 1995. New rest-breaking agents for the control of delayed foliation of apples. Acta Hort. 409:151-154.

Prive, J.P., D.C. Elfving, and J.T.A. Proctor. 1988. Pedicel characteristics of four apple cultivars. Fruit Var. J. 45(4):122-125.

Prive, J.P., D.C. Elfving, and J.T.A. Proctor. 1989. Paclobutrazol, gibberellin, and cytokinin effects on growth, development, and histology of apple pedicels and fruits. J. Amer. Soc. Hort. Sci. 114(2): 273-278.

Sagredo, K.X. 2008. Effect of rest-breaking and fruit thinning treatments on reproductive development in apple. Stellenbosch Univ., Stellenbosch, PhD (Agric.) Diss.

Unrath, C.R. 1999. Prohexadione-Ca: a promising chemical for controlling vegetative growth of apples. HortSci. 34(7):1197-1200.