PRODUCTION OF THE POLLINATION CONSTANT ASTRINGENT PERSIMMON 'TRIUMPH' UNDER SOUTH AFRICAN CONDITIONS

By

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature:……………….. Date:…………………….

SUMMARY

Persimmon production is new to the Western Cape region of South Africa and is well suited to its Mediterranean climate. Export market opportunities for out-of-season fruit in traditional Northern Hemisphere markets have led to the planting of almost 700 ha of the astringent cultivar 'Triumph' since 1998. Production of other cultivars is negligible compared to 'Triumph'. There is a need to study the vegetative and reproductive phenology of 'Triumph' in order to improve production under local conditions.

In order to determine the physical characteristics of good bearing units, the effect of length and orientation of one-year-old shoots on bud break, vegetative growth, flowering, fruiting and fruit quality was evaluated. Further trials were conducted to determine the duration of the flowering period, flower distribution on one-year-old shoots and the timing of flower initiation. Shoots between 30-60 cm, the longest length studied, produced the most new vegetative growth, had the most flowers, and set the most fruit. Fruit also ripened faster on 30-60 cm shoots compared to shorter shoots. Shoots with more flowers were thicker than shoots of equal length, but with fewer flowers.

Poor fruit set is one of the most important problems in persimmon cultivation. Experiments were conducted to determine the efficacy of gibberellic acid (GA_3) and scoring or girdling during full bloom (FB) to increase fruit set and yield. Different GA_3 concentrations (20 $mg \cdot L^{-1}$ and 40 $mg \cdot L^{-1}$) were evaluated. GA_3 applications and scoring/girdling were applied at 30% FB or 30 and 70% FB. While GA_3 treatments were ineffective, scoring increased fruit set and yields in young orchards (< 5-year-old) up to three times. In general, GA_3 sprays decreased fruit size although it did not increase the number of fruit per tree. In more mature orchards (> 5 years old), scoring or girdling in combination with GA_3 applications at 30 and 70% FB increased yield by an average of 16 tons (45%) compared to GA_3 treatment on its own (35 tons). This increase in yield did not affect fruit size. Girdling and scoring were equally effective in increasing yield. When it comes to GA_3 applications to improve fruit set in mature orchards, producers must bear in mind that 30% full bloom occurs already 2 to 4 days after the first flowers are open. Based on these data, guidelines to manage fruit set can be developed for the South African persimmon industry. However, these guidelines will also need to entail pruning and thinning strategies to prevent alternate bearing that may result from the high yields. 'Triumph' preferentially initiates flowers laterally in terminal quadrants of

one-year-old shoots. This has to be taken into consideration with the development of pruning strategies. When timing thinning treatments, producers should keep in mind that flower initiation starts shortly after shoot elongation has ended and soon after fruit set.

The short harvesting period of ‘Triumph’ puts pressure on producers and packing facilities, and shortens the marketing window of fruit. The final objective of this study was to advance or delay harvesting by using scoring or plant growth regulators. The effect of these treatments on fruit quality at harvest and after storage for 3 months at -0.5°C and shelf life of 5 to 7 days at 15°C were evaluated over two seasons. n-Propyl dihydrojasmonate (PDJ), aminoethoxyvinylglycine (AVG) and scoring generally did not affect fruit ripening and storability. 2-Cloroethyl phosphonic acid (ethephon) applied at 24 $mg{\cdot}L^{-1}$ 4 weeks before the first of two harvest dates (WBFH) advanced ripening. Gibberellic acid (GA_3) application at 50 $mg{\cdot}L^{-1}$ 2 WBFH and 1-methylcyclopropene (MCP) applied immediately after harvest, delayed fruit ripening and reduced fruit softening during storage and shelf life. Future research should evaluate combined treatments of ethephon with MCP or GA_3 to advance harvesting without negatively effecting storability of fruit.

PRODUKSIE VAN DIE VRANK PERSIMMON 'TRIUMPH' ONDER SUID-AFRIKAANSE TOESTANDE

OPSOMMING

Verbouing van persimmon is 'n nuut tot die Wes-Kaap streek van Suid-Afrika met sy geskikte Mediterreense klimaat. Uitvoergeleenthede vir buite-seisoen vrugte na tradisionele Noordelike Halfrond markte het sedert 1998 gelei tot die aanplant van bykans 700 ha van die vrank cultivar, 'Triumph'. Ander cultivars word ook verbou, maar die hoeveelhede is weglaatbaar in vergelyking met 'Triumph'. Daar bestaan 'n behoefte om die vegetatiewe en reproduktiewe fenologie van 'Triumph' te bestudeer ten einde produksie onder plaaslike toestande te verbeter.

Die effek van lengte en oriëntasie van een-jaar-oue lote op knopbreek, vegetatiewe groei, blomtyd, vrugset en vrugkwaliteit is geëvalueer ten einde die fisieke eienskappe van goeie dra-eenhede te bepaal. Verdere proewe is uitgevoer om die duur van die blomperiode, die verspreiding van blomme op een-jaar-oue lote en die periode van blominisiasie te bepaal. Lote tussen 30–60 cm, die langste lengte wat bestudeer is, produseer die meeste nuwe vegetatiewe groei, het die meeste blomme en set die meeste vrugte. Vrugte op 30–60 cm lange lote het ook vinniger ryp geword in vergelyking met vrugte op korter lote. Lote met baie blomme was dikker as lote van dieselfde lengte, maar met minder blomme.

Swak vrugset is een van die belangrikste probleme wat persimmon produksie kniehalter. Eksperimente is uitgevoer om te bepaal of toediening van gibberelliensuur (GA_3) en insnyding (*scoring*) of ringelering gedurende volblom (VB) effektief is om vrugset en produksie te verhoog. Verskillende GA_3 konsentrasies (20 $mg \cdot L^{-1}$ en 40 $mg \cdot L^{-1}$) is geëvalueer. GA_3 toegediening en insnyding/ringelering is uitgevoer by 30% VB of by 30% en 70% VB. Terwyl GA_3 ondoeltreffend was in jong boorde (< 5-jaar-oud), het insnyding vrugset en produksie tot drie keer verhoog. GA_3 het vruggrootte oor die algemeen verminder sonder dat daar 'n toename in die aantal vrugte per boom was. In meer volwasse boorde (>5-jaar-oud) het insnyding/ringelering in kombinasie met GA_3 toediening by 30 en 70% VB, produksie met gemiddeld 16 ton (45%) verhoog in vergelyking met net GA_3-behandeling (35 ton). Hierdie verhoging in produksie het geen effek op vruggrootte gehad nie. Ringelering en insnyding was ewe effektief in die verhoging van produksie. Met die toediening van GA_3 in volwasse

boorde moet produsente in gedagte hou dat 30% VB bereik kan word binne 2 tot 4 dae nadat die eerste blomme oopgegaan het. Bogenoemde data stel ons in staat om riglyne vir die bestuur van vrugset te ontwikkel vir die Suid-Afrikaanse persimmon bedryf. Ten einde die ontstaan van alternerende drag as gevolg van hoë vrugladings te vermy, sal snoei- en uitdunstrategieë egter in ag geneem moet word met die saamstel van hierdie riglyne. 'Triumph' inisieer blomme hoofsaaklik lateraal in die terminale kwadrante van een-jaar-oue lote. Dit moet in aanmerking geneem word met die ontwikkeling van snoeistrategieë. Met die tydsberekening van uitdunbehandelings, moet produsente in gedagte hou dat blominisiasie in aanvang neem kort na lootgroeistaking en vrugset plaasgevind het.

Die kort oesperiode van 'Triumph' plaas produsente en verpakkingsaanlegte onder druk, en verkort die bemarkingsvenster van vrugte. Die laaste doelwit van hierdie studie was om oes te vervroeg of uit te stel deur gebruik te maak van insnyding of plantgroeireguleerders. Die effek van hierdie behandelings op vrugkwaliteit met oes, na opberging vir 3 maande by -0.5 ^{o}C en raklewe van 5 tot 7 dae by 15 ^{o}C is geëvalueer oor twee seisoene. N-propieldihidrojasmonaat (PDJ), amino-etoksievinielglisien (AVG) en insnyding het oor die algemeen geen effek op die rypwording en opbergingsvermoë van vrugte gehad nie. Toediening van 2-chloro-etielfosfiensuur (ethephon) teen 24 $mg{\cdot}L^{-1}$, 4 weke voor die eerste van twee oeste het rypwording versnel. Toediening van gibberelliensuur (GA_3) teen 50 $mg{\cdot}L^{-1}$ 2 weke voor die eerste oes en 1-metielsiklopropeen (MCP) onmiddelik na oes, het rypwording vertraag en het die sagword van vrugte gedurende opberging en raklewe verminder. Ten einde oesdatums te vervroeg sonder om die opbergingsvermoë van vrugte te benadeel, behoort die kombinasie van ethephon met MCP of GA_3 geëvalueer te word.

Dedicated to my father Ferdie, my mother Anchen and my sister Alida

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TABLE OF CONTENTS

GENERAL INTRODUCTION

The persimmon (*Diospyros kaki* L.) is a deciduous fruit tree that is primarily grown in temperate regions of the world (Kitagawa and Glucina, 1984). Export market opportunities for out-of-season fruit in traditional Northern Hemisphere markets has seen to the establishment of almost 700 ha of ‘Triumph’ persimmons in the Mediterranean Western Cape region of South Africa since 1998. In order to produce persimmons in South Africa, production practices need to be adapted to comply with local growing conditions. Fine-tuning of tree training and pruning strategies requires an understanding of the vegetative and reproductive phenology of the persimmon under local conditions. Firstly, a literature study was done on the vegetative and reproductive biology of persimmons in general. Factors that influence reproductive development and manipulations to improve reproductive flower initiation and fruit set were reviewed. Unfortunately, literature on persimmons is difficult to access, as most of the publications are written in Asian languages.

As the first aim of the study, we studied the bearing habit of ‘Triumph’, and in particular the characteristics of reproductive one-year-old shoots. Aspects such as timing of flower initiation, timing of flowering and duration of full bloom were assessed. This knowledge is also needed to develop methods to address problems such as poor fruit set in persimmon cultivation (Kitagawa and Glucina, 1984). The use of GA_3, girdling and combination of the two treatments were evaluated to provide South African persimmon growers with guidelines for improving fruit set.

A further problem that complicates persimmon production in South Africa is that the harvest season of ‘Triumph’, the only cultivar planted, lasts only 2 to 3 weeks during which time all the fruit are picked and transported to the packhouse. Ripening of persimmon fruits can be manipulated by application of plant growth regulators (Flohr et al., 1993). Previous studies have shown that the harvest window can be extended at both ends by applying different plant growth regulators such as ethephon (Kim et al., 2004) and GA_3 (Ben-Arie et al., 1986). The use of pre- and post-harvest treatments to delay or advance the maturity of ‘Triumph’ persimmons was evaluated. The effect of these treatments on storage potential and shelf life were also determined.

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LITERATURE REVIEW: VEGETATIVE AND REPRODUCTIVE BIOLOGY OF PERSIMMONS

1. INTRODUCTION

The Japanese or Oriental persimmon (*Diospyros kaki* L) is a deciduous fruit tree belonging to the ebony (Ebenaceae) family (Kitagawa and Glucina, 1984; Mowat et al., 1995; Yonemori, 1997). The persimmon is native to temperate China, but has first been cultivated in Japan where it is regarded as the national fruit (George et al., 1994). Although regarded as a temperate zone species, the persimmon readily adapts to a wide range of climates ranging from temperate (Japan, New Zealand), Mediterranean coastal regions (France, Italy), subtropical (Australia) to semi-tropical (Florida) (Table 1; Morton, 1988; Mowat and George, 1994).

Table 1. Latitude and mean monthly temperatures of persimmon-growing locations (adapted from Mowat and George, 1994).

Sites	Latitude	Mean monthly temperature	
		Minimum ^{o}C	Maximum ^{o}C
Batumi, Georgia	41.37 N	2.0	25.0
Fukushima, Japan	41.31 N	-3.0	30.5
Pulsan, South Korea	35.06 N	-3.0	30.5
Nara, Japan	34.41 N	-0.5	32.0
Xian, China	34.16 N	2.5	31.5
California, USA	34.00 N	8.0	28.0
Haifa, Israel	32.49 N	9.5	32.0
Cairo, Egypt	30.03 N	5.0	35.5
Chang sha, China	28.10 N	6.0	30.0
Florida, USA	25.29 N	12.0	32.5
Canton, China	23.08 N	8.5	32.5
Sao Paulo, Brazil	22.34 S	13.0	30.0
Queensland, Australia	26.40 S	16.0	29.0
Santiago, Chile	33.16 S	3.0	29.0
Loxton, South Australia	34.38 S	4.0	31.0
Kerikeri, New Zealand	35.12 S	10.0	20.0
Hastings, New Zealand	39.39 S	7.5	19.5

Persimmon cultivars are broadly classified into two groups namely astringent or non-astringent, based on their levels of H_20-soluble tannins at maturity (Mowat et al., 1997). A further distinction is made between pollination constant and pollination variant cultivars (Kitagawa and Glucina, 1984; Sugiyama and Yamaki, 1994). Pollination constant cultivars show no change in flesh colour after pollination while the flesh of pollination variant cultivars is light coloured when seedless, but dark reddish brown when seeded.

Although persimmons have long been grown in home gardens in South Africa, a persimmon industry is only now being established in the Mediterranean Western Cape region with ± 700 ha planted to 'Triumph' since 1998. 'Triumph' is a late-maturing, pollination constant astringent cultivar with good storability (Rabe, 2003). As persimmon cultivation is new to South Africa, it is imperative to study the phenology of 'Triumph' under local conditions in order to optimise production practises. The main aim of this review is to focus on the vegetative and reproductive biology of persimmons in general. Factors that influence reproductive development and manipulations to improve reproductive development and fruit set are discussed, bearing in mind that attaining regular high yields of good quality is the primary horticultural concern of the industry.

2. PHENOLOGY

2.1. Bud break, shoot and root growth

Persimmon trees have a dormant period of 3 to 4 months, but require relatively little chilling for dormancy release compared to other deciduous fruit crops (Fig. 1; Mowat et al., 1995). In Queensland, Australia, persimmons are successfully grown at sites with low chilling (100-200 h below 7.2°C) (Mowat et al., 1995). However, bud break proceeds faster and is more uniform in production areas that receive more than 300 chill units (Sharpe-Weinberger model) (George et al., 1994).

Vegetative bud break in 'Triumph' occurs late in September in South Africa (personal observation). Poor or delayed bud break may occur in trees with low carbohydrate reserves (Mowat et al., 1995). This may result from either over cropping in the previous season, root damage or premature leaf fall due to hail, water stress or disease. Persimmon shoots extend rapidly after bud break and terminate growth after about 4 to 6 weeks (Fig. 1; Kitagawa and Glucina, 1984; George et al., 1994). Shoot growth increases with increasing temperature (Fumuro, 2003). Studies show that 'Fuyu' persimmon leaves become net exporters of carbohydrates about 21 days after bud break (George et al., 1994). A second growth flush may occur during mid summer on young vigorous trees (Fig. 1). These shoots may not mature before winter, resulting in the production of low quality fruit. The second growth flush may occur due to high soil fertility or mild climatic conditions (Kitagawa and Glucina, 1984). According to George et al. (1994), persimmon surface roots display a strong growth flush during midsummer followed by a weaker flush during late-summer (Fig. 1). Root growth does not commence until after bud break.

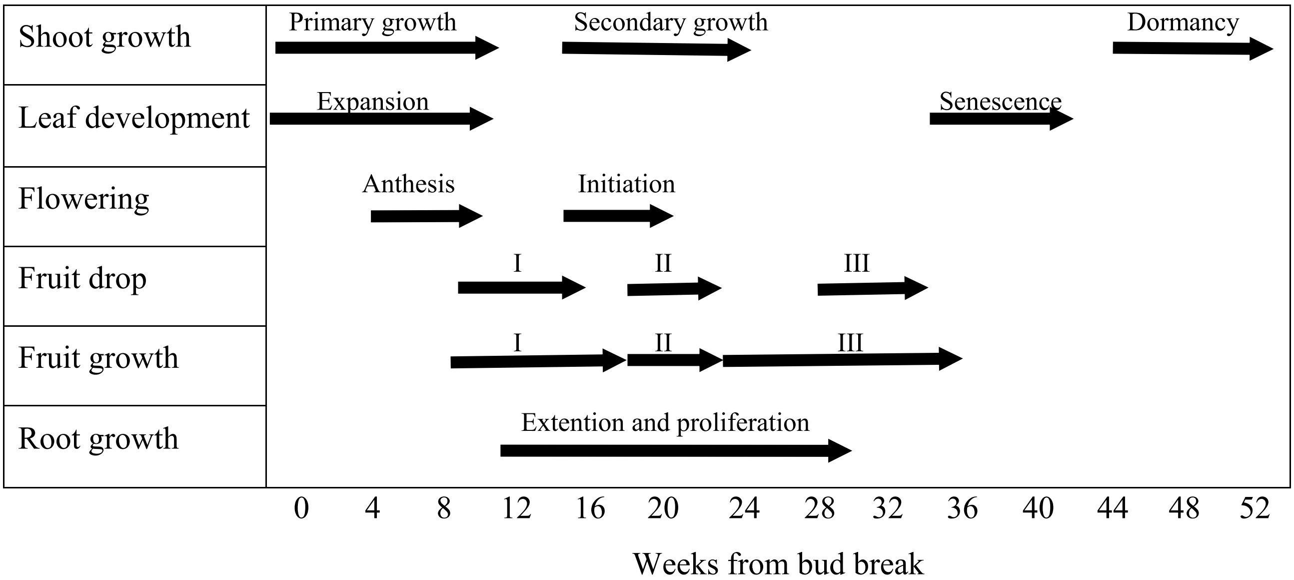

Figure 1. The phenology of the persimmon (adapted from Mowat and George, 1994).

2.2 Flower initiation and development

Persimmons produce three types of flowers: female (pistillate) flowers, male (staminate) flowers, and hermaphrodite or bisexual (perfect) flowers (Kitagawa and Glucina, 1984). Female flowers are single and can be distinguished from male flowers by their large, dark green, four-lobbed calyxes (Morton, 1988). The male flowers (the ovary is non-functional) are usually much smaller than the female flowers and occur in two- to three- flowered clusters on small, weaker shoots (Kitagawa and Glucina, 1984). Hermaphrodite (perfect) flowers can normally be found among normal male flowers in the centre position in a cluster of three (Kitagawa and Glucina, 1984; Morton, 1988). Persimmon trees are monoecious, dioecious or polygamous*. The economically important cultivars, including 'Triumph', are dioecious (Kitagawa and Glucina, 1984). Fruit are set parthenocarpicaly and are seedless (Blumenfeld, 1981). However, rootstock suckers with male flowers may give rise to significant numbers of

* Polygamous – hermaphrodite flowers together with male or female flowers, or both, all on the same plant.

undesirable seeded fruits. Flower initiation occurs more or less 12 weeks after bud break (Fig. 1; Mowat and George, 1994). Flowers start developing in the first three to four most distal lateral buds of shoots after the termination of shoot growth and after the production of new leaf primordia within the bud have ceased (Mowat and George, 1994). Shoots arising from these buds bear two to four single female flowers (the stamens are sterile) in the axils of the more basal nodes (Kitagawa and Glucina, 1984; Mowat and George, 1994). Only the sepals and petals differentiate prior to the winter rest period and all other development occurs during spring (Moncur, 1988 cited in Mowat and George, 1994). Flowers open soon after pre-formed leaves have matured in spring, about a month after bud break (Kitagawa and Glucina, 1984). In South Africa, flowering in 'Triumph' occurs from mid October (personal observation). Since flower initiation occurs during fruit development, conditions at this time determine whether flowers are formed or whether the meristems remain vegetative. The proportion of meristems that become reproductive depends on a great number of correlative factors, such as the number of simultaneously growing fruit, the number and vigour of vegetative meristems, the presence of mature leaves and the activity of roots (Bangerth, 2005). Shoots terminating growth early in the growing season have a greater ability to differentiate flower buds than those terminating in the mid or late part of the growing season (Glucina and Toye, 1985 cited in Mowat and George, 1994).

2.3. Fruit set

High yields depend primarily on adequate flowering and subsequent fruit set (Albrigo and Saúco, 2004). Therefore, the fruit set period represents a critical stage in the production cycle of many tree crops (Martinez-Cortina and Sanz, 1991). Fruit set involves retention of ovules that respond to pollination and fertilisation so that seeds are produced or otherwise ovules receive sufficient assimilates, hormones, nutrients and water to continue growth as parthenocarpic fruit, whether fertilized or not (Albrigo and Saúco, 2004). As already mentioned, 'Triumph' sets fruit parthenocarpically (Blumenfeld, 1981). Parhenocarpy involves development of fruit without fertilisation and seed formation (Kitagawa and Glucina, 1984; de Menezes et al., 2005). This may result from ovary development without pollination (e.g. citrus, banana, and pineapple), from fruit growth stimulated by pollination, but without fertilisation taking place (e.g. certain orchids), or from fertilisation followed by abortion of the embryos (e.g. grapes, peaches and cherries) (Salisbury and Ross, 1992). Astringent persimmon cultivars, e.g., 'Triumph', normally set fruit without pollination more easily than do non-astringent cultivars (Kitagawa and Glucina, 1984).

2.4. Fruit development

The persimmon fruit exhibits a double sigmoidal growth curve divided into three stages; two active stages of growth, stage I and stage III separated by a less active stage II (Fig. 1; Kitagawa and Glucina, 1984; George et al., 1994; Itai et al., 1997; Nakano et al., 1997b). Growth stage I is thought to be associated with cell division/differentiation and growth stage III with cell expansion/maturation (Nakano et al., 1997b). Retarded fruit growth during stage II has been ascribed to very high day and night temperatures during summer (Kitagawa and Glucina, 1984; Mowat et al., 1995). Temperatures of 30 °C or greater have been found to extend stage II of fruit development delaying fruit maturation (Sugiura et al., 1991; Mowat et al., 1995). Fruit development ranges from 120 to 190 days depending on cultivar and environment (Otani, 1961 cited in Mowat and George, 1994). 'Triumph' fruit has a development period of about 180 days in South Africa (personal observation).

Persimmon fruit have relatively large calyx leaves compared with other fruits (Nakano et al., 1997a). At flowering time the calyx contributes more than 50% to the fruit weight (Kitagawa and Glucina, 1984). Unlike the fruit skin, calyx leaves have many stomata and seems to be the photosynthetic organ of the fruit. Calyx leaves have a large effect on fruit growth particularly during stages I and II of development (Kitagawa and Glucina, 1984). Nakano et al. (1997a) found that the calyx leaves of persimmon fruit have a very high photosynthetic ability and is responsible for almost all of the fruit's photosynthesis. Fruit growth and maturation during growth stage III can be inhibited by calyx leaf removal (Nakano et al., 1997b). Therefore, it is important to keep calyx leaves intact and healthy throughout fruit development.

2.5. Fruit and flower abscission

Flower and fruit drop is an important problem in persimmon cultivation (Kitagawa and Glucina, 1984). However, the abscission process in persimmon has not been fully clarified (Kitajima et al., 2003). Abscission is a complex process that starts with the induction stage and terminates with shedding of plant organs. Many physiological and biochemical steps, under hormonal control, regulate this process (Pandita and Jindal, 2004).

At least three mechanisms are involved in the regulation of pre-anthesis ovary development in apple (Bangerth, 2004):

1. Limitations in nutrient/carbohydrate supply;
2. Hormonal regulation;
3. Interactions between 1 and 2;

In apple, competition or, more likely, dominance, occurs already pre-anthesis inside the developing flower bud. The development of these pre-anthesis differences is the result of dominance effects exerted by the earlier initiation of one of the flowers and by other plant organs such as simultaneously developing fruit and vegetative shoots. This earlier start of an organ's development (primigenic dominance) usually causes it to dominate over other organs (Bangerth, 2005). The flowers that are most inhibited are those that differentiate later and are, therefore, hormonally dominated by the earlier developing organs (Bangerth, 2004). Abscission of the dominated organs occurs in situations of severe dominance (Bangerth, 2004) or carbohydrate limitation (George et al., 2004). Under these conditions, many flowers undergo a climacteric rise in respiration and ethylene production (Marynick, 1977). The ethylene eventually causes senescence (Salisbury and Ross, 1992). The degree to which primigenic or positional effects contribute to dominance relationships between persimmon flowers within the bud or on the shoot is uncertain.

3. FACTORS THAT INFLUENCE REPRODUCTIVE DEVELOPMENT

3.1. Correlative factors

Fruit trees generally display an antagonistic relationship between shoot growth and reproductive bud development (Monselise and Goldschmidt, 1982). Young leaves are rich sources of gibberellic acid (GA_3) thought to inhibit flower-bud formation. Hence, in pome fruit, flower bud formation is inhibited as long as shoot growth continues and young leaves are present (Tromp, 2000). Persimmon shoots terminating growth early in the growing season have a greater ability to differentiate flower buds than those terminating in the mid or late part of the growing season (Mowat and George, 1994). However, in apple, too weak vegetative growth reduces the number of potential bearing positions and has a negative effect on reproductive bud development (Tromp, 1976). This also seems to be the case in persimmon (personal observation).

The inhibitory effects of treatments such as defoliation, shading and leaf injury have established that the presence of mature leaves is a prerequisite for reproductive bud formation in pear (Tromp, 2000). It is thought that either a leaf-produced hormonal factor is vital for flower production, or that leaves cause the redistribution of hormones from elsewhere via the transpiration stream (Tromp, 2000). Leaves play an important role in the accumulation of nitrogenous compounds and carbohydrates reserves in woody parts of deciduous fruit trees during autumn (Oliveira and Priestley, 1988; Titus and Kang, 1982). In persimmon, these reserves play an important role in flower bud development, and in early growth of shoots and fruits the following year (Choi et al., 2003).

In fruit species displaying alternate bearing, the presence of fruit seems to be a key factor controlling flower initiation. This is either by producing hormones which inhibit flower initiation as in citrus (Bower et al., 1990), apple (Prang et al., 1997) and pistachio (Vemmos, 1999) or by acting as strong sinks for assimilates and competing with the meristems initiating flower buds (Bower et al., 1990; Vemmos, 1999). Flower buds compete poorly with other sinks for metabolites, resulting in carbohydrate deficiency, which is possibly responsible for bud abscission (Vemmos, 1999). In contrast, accumulation of reserves during the ‘off’ year promotes heavy flowering in the subsequent year in citrus (Bower et al., 1990), persimmon (Collins and George, 1997) and pistachio (Vemmos, 1999).

3.2. Environmental factors

Climatic conditions can influence the productivity of persimmon by affecting flower development and fruit set (Mowat et al., 1995). Good light distribution in the fruiting canopy is very important (Kitagawa and Glucina, 1984). Flower initiation and fruit set have been positively correlated with the total sunshine hours during spring and late summer (Mowat et al., 1995). Canopy shading can reduce yields by reducing fruit set and stimulating fruit drop as fruit on shoots growing in shaded areas of the canopy are more prone to drop than fruit on exposed shoots (Mowat et al., 1995; Yakushiji et al., 1997; Mowat, 2003). Low irradiance (14 MJ m^{-1} day^{-1} or less) can significantly increase fruit drop after fruit set while less than 6 MJ m^{-1} day^{-1} can prevent fruit set (Mowat et al., 1995). Processes such as assimilate partitioning or synthesis and redistribution of hormones (e.g. abscisic acid), which can be modified by environmental cues, are likely to affect abscission. For example, high abscisic acid (ABA) concentration and low light intensity have been shown to decrease polar auxin transport and therefore lowering the sink strength of pepino fruit (Prohens and Neuz, 2001).

High spring temperatures can increase shoot vigour, thereby causing a reduction in flower size and increased flower and fruit abscission (Mowat et al., 1995). Furthermore, excessive shoot growth during stage I of fruit development can cause fruit drop due to shading or competition for assimilates (Kitagawa and Glucina, 1984; Mowat, 2003). According to Ko (1997), pruning can reduce excessive shoot growth and allow for sufficient sunlight penetration in the canopy. Dennis (1994) emphasises that orchard practises plays an important role in optimising flowering and fruit set, thereby assuring optimum cropping and large fruit size.

Water stress and water logging during anthesis and fruit set in persimmons can adversely affect fruit set and stimulate fruit drop (Mowat et al., 1995). However, fruit drop in potted persimmon trees only occurred once the drought became severe enough to cause defoliation (Kitagawa and Glucina, 1984). Fruit set can also be influenced by a reduction in canopy assimilation through physical damage to the leaf canopy by hail, pest or wind damage during early stages of flower and fruit development (Mowat et al., 1995).

3.3. Physiological factors

3.3.1. Nutrients and assimilates

Tree nutrition may also play a role in the regulation of flower bud differentiation in persimmon (Kitagawa and Glucina, 1984). Leaf nutrients such as N, K, Ca and Mn show significant relationships with crop load. With the exception of N, all of these nutrients decrease in concentrations as crop load increases, particularly in the case of K, a nutrient known to be required at high levels by persimmon (Collins and George, 1997). Flower and fruit drop may be increased by excessive N application due to stimulation of vegetative growth (Dennis, 1994; Ko, 1997; Prohens and Neuz, 2001). However, low N levels may be equally detrimental to fruit set (George et al., 2003). Late summer and autumn N application on persimmon trees have been shown to increase the accumulation of starch reserves for the following season's flowering and fruit set by maintaining leaf health (George et al., 2003). In apples, late summer applications of N improve flower quality. Since late application of N postpones leaf senescence and abscission, the promotive effect of N may be mediated through enhanced levels of assimilates for meristematic activity in the bud, which leads to better flower differentiation (Williams, 1965).

The growth of a plant organ may be restricted by assimilate availability (source limitation) or by the organ's ability to utilize assimilates (sink limitation) (Patrick, 1988). The partitioning patterns of photosynthate between shoot growth and flower development early in the season influence fruit set and development (Quinlan and Preston, 1971). Wardlaw (1990) prioritised sink strength of plants in the following order: seeds > fleshy fruit parts = shoot apices and leaves > cambium > roots > storage. The strength of a fruit sink depends on its size, the time of its initiation relative to other sinks, its location, and its distance from the source (Bangerth and Ho, 1984). Source-sink relationships and the regulation of carbon allocation therefore influence yields.

3.3.2. Plant hormones

The past few years have seen considerable progress being made in the understanding of hormonal regulation in plants and in fruit developmental processes (Bangerth, 2005). Fruit trees need a multitude of correlative signals for optimum growth and development and in order to maintain homeostasis with their environment (Bangerth, 1993).

3.3.2.1. Flower initiation

Of all known plant hormones, gibberellins (GA) are most strongly associated with flowering (Goldschmidt and Samach, 2004). GA strongly inhibits flower initiation in various fruits, i.e., apples, apricot, mango and nectarines (Goldschmidt et al., 1997). However, no literature could be found on the effect of GA on flower initiation in persimmons.

The correlative influence of the apex of a growing shoot on the growth of auxiliary buds (apical dominance is most likely mediated by the polar auxin transport system (Li et al., 1995). Bangerth (2000) suggest that differences in IAA export from, and transport capacities of, dominant and dominated shoots, may be explained by a mechanism of auxin transport autoinhibition, whereby the earlier and stronger export of IAA from the dominant shoot inhibits auxin export from the dominated shoot at the point where the two streams converge. Interactions of this kind can be demonstrated e.g., i) inhibition of lateral buds and shoots by terminal buds, ii) growth rate of shoots, regulating to some extend of flower bud initiation, iii) dominance relationships between fruits regulating fruit set, fruit drop and fruit growth (Bangerth, 1993).

Cytokinins (CK) are associated with promotion of reproductive bud formation and flower differentiation (Roitsch and Ehneß, 2000). According to Ramírez et al. (2004), exogenous application of cytokinins promotes fruit bud initiation in apple trees. Flower bud formation in apple trees and grapevines is related to a gibberellin:cytokinin balance (Lavee, 1989; Goldschmidt et al. 1997; Buban, 2000).

3.3.2.2. Fruit set

The application of GA_3 stimulates parthenocarpy and alleviates fruit drop in persimmon (Blumenfeld, 1981; Sugiyama and Yamaki, 1994). Exogenous application of GA_3 and/or GA_{4+7} also promotes fruit set and parthenocarpic fruit development in various other fruits, i.e., apple (Bangerth and Schröder, 1994), loquat (Sadamatsu et al., 2004), peach (Stutte and Gage, 1990), pear (Deckers and Schoofs, 2002), and tomato (Fos et al., 2001). In seedless 'Clementine' mandarin, the positive effect of GA_3 on fruit set was explained by applying PP333, a GA_3 synthesis inhibitor, which increased fruit abscission. This effect was completely suppressed by the exogenous application of GA_3 (Talon et al., 1992). The effect of GA_3 on parthenocarpic fruit set has been ascribed to an increase in fruit sink strength (Stutte and Gage, 1990).

Fruit drop is regulated by a complex of dominance/competition interactions between neighbouring fruits and/or shoots (Bangerth, 2000). The basipolar auxin transport system regulates these organ interactions. The system entails that the dominant fruit is able to retard the growth rate of another fruit that it dominates (Bangerth, 2004). Moderate dominance results in a reduced growth rate, strong dominance in fruit abortion (Bangerth, 2000). Blanusa et al. (2005) explains that the IAA transport through the abscission zone (AZ) of the dominated fruit declines to a level where its resistance to ethylene is lowered to a threshold level thus initiating the abscission process.

Ethylene is a natural regulator of abscission (Hall and Lane, 1952). The IAA status of the abscission zone is a major factor regulating its sensitivity to ethylene, as IAA delays or prevents senescence in apple (Pandita and Jindal, 2004). According to Bangerth (2004), it remains an open question whether ABA is another primary player in the abscission process or whether it acts more indirectly. In the latter case at least two possibilities could account for an ABA effect: (i) ABA retards the growth rate of the fruit, which then indirectly affects abscission, (ii) ABA increases the sensitivity of the abscission zone to ethylene (Talon et al., 1997, Blanusa et al., 2005).

Parthenocarpic fruit set causes a rapid decline in ABA levels leading to fruit growth and cell division. This decline in ABA levels may remove a block in cell division, but is probably not sufficient to cause continued fruit growth (Bangerth, 1998). High concentrations of GA in combination with CK are required to induce and sustain high levels of parthenocarpic fruit set in most apple and pear cultivars (Bangerth and Schröder, 1994). Exogenous applications of GA and CK lead to higher concentrations of these hormones in the pericarp of fruit and may have several functions; (i) reducing the ABA concentration in the ovule, (ii) re-initiating cell division, (iii) stimulating cell growth and (iv) increase sink activity (Bangerth, 2004). It has been shown that the auxin content of ovaries in flower buds from varieties of oranges, lemons and grapes that produce fruits parthenocarpically is higher than in the ovaries of varieties that do not produce fruits parthenocarpically (Gustafsen, 1939).

To summarise the effects of hormones on reproductive development; a developing bud dominated by a fruit or shoot with high auxin export will develop slowly and this will lead to the formation of poor quality flowers. On the other hand, a bud that develops under low inhibition of other fruit and shoots will start to develop earlier than the strongly inhibited bud, which will lead to flowers of superior quality. The assumption is made that the ability to export IAA is essential for a growing organ. If this export does not take place or is inhibited, for instance because of the proposed autoinhibition, the growth of the specific organ may be reduced or it may abscise (Bangerth, 1989). CK will stimulate cell division, which will raise the metabolic activity and ultimately increases sink strength and the degree of dominance over the developing bud (Li et al., 1995). During flower induction, high levels of CK will increase the number of reproductive buds induced and high levels of CK during flower initiation and differentiation will improve flower quality (Roitsch and Ehneß, 2000). Exogenous application of GA leads to the reduction in ABA levels and promotes parthenocarpic fruit set.

4. MANIPULATIONS INFLUENCING REPRODUCTIVE DEVELOPMENT

Before there is any change of morphology, i.e. during induction, the meristem of the bud is programmed to form flowers by some unknown signal or some biochemical stimulus (Tromp, 2000). The transition from the vegetative to the generative state is usually irreversible (Buban and Faust, 1982). This means that manipulation of flower bud formation is restricted mainly to the induction phase occurring early in the growing season. Several treatments may affect flower differentiation and, therefore, flower quality after induction has occurred, but the number of reproductive buds is not influenced (Tromp, 2000). In persimmon, flower initiation takes place as soon as a terminal bud has formed on the current season's growth and the production of new leaf primordia within the bud has ceased (Mowat and George, 1994).

4.1. Girdling

With girdling, the phloem is completely severed by the removal of a cylinder of bark from the trunk without damage to the underlying tissue (Noel, 1970). Scoring is a form of girdling in which a narrow incision is made around the circumference of the trunk. Although the mechanism through which girdling acts is not yet clearly understood, it has been shown that girdling is an effective technique to reduce vegetative growth, promote flowering, improve fruit set, increase fruit size and advance maturity in apples (Pretorius et al., 2004), litchi (Li and Xiao), 2001, persimmon (Hasegawa et al., 2003), macadamia (Trueman and Turnbull, 1994), mango (Rebouças and José, 1997) and nectarines and peaches (Agenbach, 1990).

The removal of a strip of bark from the trunk interrupts basipetal IAA and phloem transport and improves metabolite availability for developing organs above the girdle in the upper canopy (Li and Xiao, 2001; Ramburn, 2001). Water and mineral transport from the roots to the canopy is not directly affected (Goren et al., 2004). In the hierarchy of sinks, fruit and shoots are equal (Wardlaw, 1990), but since shoots develop prior to fruits they compete more effectively for carbohydrates during the early season (Bangerth and Ho, 1984). The redistribution of assimilate supply and changes in plant growth regulator content between different plant organs appears to be the primary effect of girdling or scoring, with the growth of fruit being favoured over the growth of vegetative organs (Wallerstein et al., 1973; Dann et al., 1984). Reduced leaf area per unit fruit number, together with reduction in leaf size, limb circumference growth, lateral shoot length and internode length reflect this change on girdled peach trees (Dann et al., 1984).

Polar IAA transport is thought to be the principle facilitating factor in correlative growth control (Bangerth, 1989). Girdling disrupts this basipetal hormone signal (Noel, 1970) as evidenced by a sharp increase in IAA levels above the girdle in peach trees and a 75% reduction in the IAA concentration below the girdle (Dann et al., 1984). Bangerth (2000) also found that girdling consistently decreased IAA export from shoot tips while considerably increasing export from fruit. A possible role of IAA in apical dominance is to control the distribution and metabolism of cytokinin (CK) (Buban, 2000). The disruption of the basipetal transport of IAA leads to a rapid, short-term increase in xylem-transported CK, presumably from the roots (Bangerth et al., 2000; Li et al., 1995). This increase in CK may increase the sink activity of fruits, thereby increasing fruit set.

An alternative explanation for the effect of girdling on fruit set involves the temporary starvation of the roots and a reduction in the synthesis of cytokinins and gibberellins (Cutting and Lyne, 1993) due to the disruption of basipetal IAA and carbohydrate transport to the roots (Dann et al., 1984). The reduction in root-produced hormones somehow weakens the sink strength of shoots relative to that of fruit, which in turn increase fruit set and fruit growth. As yet there is no closure as to which of the two hypotheses to explain the mechanism by which girdling increases fruit set are right.

4.2. Thinning

Fruit thinning is used to improve fruit quality and to prevent biennial bearing. Biennial bearing has its origin in the negative effect of the presence of fruits on reproductive bud development (return bloom) (Tromp, 2000) and can be induced by not thinning at all or by insufficient thinning (Boler, 1997; Collins and George, 1997). Early removal of potential fruit (blossom thinning) is currently used in many apple and citrus producing areas to enhance flower initiation and to reduce competition for photosynthates (Monselise and Goldschmidt, 1982; Williams and Fallahi, 1999). According to Kitagawa and Glucina (1984) thinning small fruit after “June drop” is not very effective in reducing biennial bearing in persimmon, since by this time the window for flower induction has passed (Mowat and George, 1994). Although the positive effect of thinning appears to be due to the removal of fruit, this may be an over simplification by ignoring the fact that early removal of fruit stimulates shoot growth, which may reduce return bloom (Palmer, et al., 1991).

4.3. Pruning

According to Collins and George (1997), the number of new shoots can also be affected by crop load with a lowering in the number of new shoots per tree as crop load increases. High yields reduce the production of new bearing positions for the next season. New shoots can be induced by pruning in the “on” year, which may lead to a regular bearing habit (Boler, 1997).

It is particularly important to improve light distribution within the canopy in order to produce good quality flowers and to ensure more consistent annual production (Mowat et al., 1995; Mowat, 2003; Park et al., 2003; Azarenko et al., 2005). The choice of training system can influence flowering. Some trellis systems increase exposure to sunlight, resulting in better flowering. It is presumed that shading inhibits cell division and early cell enlargement of young fruit (Yakushiji et al., 1997). Therefore, light distribution within the canopy is very important in order to produce good quality fruit (Mowat et al., 1995; Mowat, 2003; Park et al., 2003). The position of fruit in the canopy influences fruit quality (Mowat et al. 1995). Exposed fruit are generally better in quality than shaded fruit (Mowat et al., 1995). Shoots shaded during early developmental stages yield smaller fruits with lower levels of soluble solids (Yakushiji et al., 1997).

5. CONCLUSION

Successful production of persimmons requires a sound knowledge of reproductive phenology as aid to decision-making regarding planting systems, pruning strategies and manipulations to obtain regular high yields of good quality fruit. ‘Triumph’ persimmon bears female flowers laterally only at the more basal nodes of current season shoots originating from lateral buds on the terminal part of one-year-old shoots. ‘Triumph’ persimmon is dioecious and sets fruit through parthenogenesis. Poor fruit set is a major problem in persimmon cultivation and is influenced by various correlative, environmental and physiological factors. Fruit set can be improved by GA_3-application and potentially by girdling.

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PAPER 1:

VEGETATIVE AND REPRODUCTIVE PHENOLOGY OF 'TRIUMPH' PERSIMMON (*Diospyros kaki* L.) UNDER SOUTH AFRICAN CONDITIONS

Abstract. **Production of 'Triumph' persimmon is new to the Western Cape region of South Africa. Hence, there is a need to establish the vegetative and reproductive phenology of the persimmon under local conditions. This is needed in order to address problems like poor fruit set, alternate bearing, tree training and pruning strategies. Trials were conducted in two production areas namely, Sonkwasdrif and Vyeboom to determine the effect of length and orientation of one-year-old shoots on bud break, vegetative growth, flowering, fruiting and fruit quality. The aim was to determine the physical characteristics of good bearing units. Further trials were conducted to determine the duration of bloom period, flower distribution on one-year-old shoots and the timing of flower initiation. Shoots between 30-60 cm produced the most new vegetative growth, had most flowers and set the most fruit. Fruit also ripened faster on 30-60 cm shoots compared to the shorter shoots. Shoots with more flowers were normally thicker than shoots of equal length but with fewer flowers. These shoots tend to have low fruit set percentages, but produce more fruit due to higher flower numbers. 'Triumph' persimmon shoots tend to bear fruit on terminal quadrants of one-year-old shoots. This has to be taken into consideration with the development of pruning strategies. Flower initiation commenced within two months after bud break. Full bloom lasted about two weeks. 30% Full bloom was reached within two to four days after the first flowers reached full bloom. Therefore, producers should closely monitor orchards to time GA_3 application for fruit set.**

The persimmon (*Diospyros kaki* L.) is a deciduous fruit tree that is primarily grown in temperate regions of the world (Kitagawa and Glucina, 1984). Export market opportunities for out-of-season fruit in traditional markets has seen the recent expansion in production of persimmons in South Africa. In order to produce persimmons in South Africa, production practices need to be adapted to comply with local growing conditions.

The growth of tree fruit species, whether they be evergreen or deciduous, follows a cyclic seasonal pattern which is repeated each year, though not necessarily on the same time scale or with the same intensity of growth for each stage (Cull, 1986). By recognizing the stages of growth and understanding their requirements and the interactions within the tree, management practices can be modified and optimised to develop strategies which lead to productivity gains (George et al., 1994).

Persimmon has a dormant period of 3-4 months, but requires relatively little chilling (100-300 hours of chilling below 7°C) for dormancy release compared with other deciduous fruit crops (Mowat and George, 1994; Mowat et al., 1995). Hence, it has been successfully cultivated in production areas with low winter chilling including the tropics (George et al., 1994). Persimmon shoots extend rapidly after bud break and terminate growth after about 4-6 weeks (Katawa and Glucina, 1984; George et al., 1994). Normally the terminal and succeeding two to three buds on well-matured shoots become reproductive after termination of shoot growth in the current season (Katawa and Glucina, 1984; Hasegawa et al., 1991). However, in 'Triumph' persimmon personal observations have shown that the terminal bud abscises. Shoots terminating early in the growing season have a greater ability to differentiate flower buds than those terminating in the mid or late part of the growing season (Glucina and Toye, 1985 cited in Mowat and George, 1994). Shoots arising from these buds bear two to four single female flowers (the stamens are sterile) at the more basal nodes (Katawa and Glucina, 1984; Mowat and George, 1994). Only the sepals and petals differentiate prior to the winter rest period and all other development occurs in the spring (Moncur, 1988 cited in Mowat and George, 1994). Flowers open soon after pre-formed leaves have matured in spring about a month after bud break (Katawa and Glucina, 1984).

In order to maximize yield of good quality fruit, it is important to understand the phenology of the tree. 'Triumph' is prone to alternate bearing. In order to understand the contribution of the vegetative component of growth to alternate bearing and to develop pruning strategies to ensure regular but adequate yield, it is important to establish the bearing habit of 'Triumph' persimmon under local conditions. We particularly need to know the characteristics of the most reproductive one-year-old shoots that will bear the best quality fruit. In order to develop methodologies to increase fruit set and to obtain regular cropping, it is also important to determine the duration of flowering and the timing of flowering. To optimise treatments aimed at improving return bloom, it is also important to establish when flower initiation takes place.

Materials and Methods

Trials were conducted in two orchards, one in Vyeboom (Latitude: 34°3'S, Longitude: 19°9'E) and one at Sonkwasdrif (Latitude: 33°20'S, Longitude: 18°59'E) region. Both regions are located in the Western Cape Province (Mediterranean climate) of South Africa. In Sonkwasdrif, trees in on *D. virginiana* rootstock were planted in 2001 at a spacing of 3.5 x 1.5 m. In Vyeboom, trees also on *D. virginiana* rootstock were planted in 1999 at a spacing of 5 x 2 m.

Effect of shoot length and orientation on bud break, flowering and fruiting (2004-2005).

One-year-old shoots of different lengths (<10, 10-30 and 30-60 cm) and orientations (vertical or horizontal) were used in this trial. Fifteen shoots per length group, per orientation (one-year-old shoots that were naturally orientated in a horizontal or upright position) were randomly selected in both Sonkwasdrif and Vyeboom and the percentage bud break, flowering, and fruiting was assessed for each shoot.

Effect of shoot length on vegetative growth and fruit quality (2004-2005).

One-year-old shoots of different lengths (<10, 10-30 and 30-60 cm) on three-year-old trees at Sonkwasdrif were used to determine the effect of shoot length on vegetative growth and fruit quality. Fifteen shoots per length group were randomly selected. Total new shoot growth was recorded and the following fruit quality parameters were assessed on 3-fruit samples: Fruit diameter (measured by electronic calliper), fruit weight and flesh firmness (determined on pared, opposite cheeks of the fruit using a GÜSS fruit texture analyser 11 mm tip). Fruit colour was assessed using a sweet persimmon colour chart (SPGT, South Africa) (values 1-8 where 8 = red/orange and 1 = green) and a Minolta chroma meter (Model CR-400, Minolta Co. Ltd., Tokyo, Japan). Hue angels (H°) range between 0° = red-purple, 90° = yellow, 180° = bluish-green and 270° = blue, and provide an appropriate means to express differences in the colour of the persimmon peel. Slices cut from each side of the fruit were juiced together and a total soluble solids (TSS) reading was taken using a refractometer (PR32, ATAGO Co. Ltd., Tokyo, Japan).

Vegetative growth, fruit quality and physical characteristics of shoots differing in flower load (2004-2005).

Ten heavy and ten light-flowering one-year-old shoots (± 30 cm in length) were randomly selected on three-year-old trees in the Sonkwasdrif production area to record vegetative growth, flowering and fruiting as well as fruit quality. Shoot diameter was measured with a digital calliper at the base of each one-year-old shoot. Total new shoot growth was measured and the total numbers of flowers as well as the total number of fruit were counted to determine the fruit set percentage. Average fruit weight per shoot was determined as well as the total fruit weight per shoot. The following quality measurements were performed on each 3-fruit sample (as previously described): Fruit diameter, flesh firmness, colour and TSS.

***Reproductive development and flowering*.**

Five randomly selected quiescent shoots (± 30 cm) in the Sonkwasdrif region were taken from 21 December 2004 every 4 weeks until 29 September 2005 to determine the date of flower initiation. Buds were dissected by light microscopy (Model SD-2PL, Kyowa Optical, Tokyo, Japan) at a 10 X/23 enlargement.

Ten one-year-old shoots (30-60 cm) were randomly selected in an orchard in the Vyeboom production area to determine the progression of flowering. Flowers were counted on 28 October 2005 in the tight bud stage to determine the total flower number per shoot. Flowers in full bloom were counted every second day starting on 31 October 2005 when the first flowers were in full bloom and used to calculate full bloom percentage for each date. Progression of flowering on one-year-old, 30-60 cm shoots in the Sonkwasdrif area (5-year-old trees) was recorded during November 2004. Shoots were divided into quadrants based on the total number of buds and the percentage of the total flowers determined per quadrant.

Results

***The effect of shoot length and orientation on bud break, flowering and fruiting*.**

Significant differences in vegetative growth on shoots of different lengths were observed in both Sonkwasdrif (Table 1) and Vyeboom (Table 2). New vegetative growth increased with increasing length of one-year-old shoots. There were significantly more new flowering shoots on the 30-60 cm long one-year-old shoots in comparison to the shorter shoot lengths. In

Sonkwasdrif, 12.5% of the new shoots borne flowers in the case of the 10-30 cm shoots compared to 40.6% on the 30-60 cm shoots (Table 1). Similarly in Vyeboom only 6% of new shoots on 10-30 cm shoots borne flowers compared to 29.0% on 30-60 cm shoots. There were significantly more flowers per new flowering shoot on 30-60 cm shoots, which resulted in significant differences in the total flower number as well as total fruit number between shoot lengths. In both regions the total number of flowers and fruit per one-year-old shoot were significantly higher for the 30-60 cm shoots compared to the <10 cm and the 10-30 cm shoots. Apart from Vyeboom where vertical shoots had a higher number of laterals compared to horizontal shoots, there were no significant differences in any of the measured parameters (Table 1, 2). There were no interactions between the length and orientation of the shoots in either region.

Effect of shoot length on vegetative growth and fruit quality.

The 30-60 cm one-year-old shoots produced significantly more new shoots than shorter shoot lengths (Table 3). Shoots <10 cm produced the least new shoots and vegetative growth. However, new growth on these shoots was still in excess of 1 m, while new growth on 30-60 cm shoots exceeded 4 m (Table 3). There were no significant differences in average length of new shoots between the three shoot lengths. In the case of fruit quality, there were no significant differences between the three shoot lengths in fruit size and colour chart values. However, there were significant differences in hue values between all the shoot lengths with the highest values for the <10 cm shoots and the lowest values for the 30-60 cm shoots. Fruit firmness also differed significantly between the <10 cm and 30-60 cm shoots with fruits on the latter being softer. Fruit on the longer shoots (10-30 cm and 30-60 cm) had significantly higher TSS values than <10 cm shoots.

Vegetative growth and fruit quality on shoots differing in flower load.

Table 4 shows that more floriferous shoots were significantly thicker than shoots of the same length, but with fewer flowers. Heavy flowering shoots also had significantly more new shoots and total vegetative growth than low flowering shoots. The average length of new shoots did not differ significantly between the two flower loads. Although the heavy flowering shoots had a significantly lower fruit set %, they still borne significantly more fruit because of their greater flower numbers. Consequently, they also had significantly higher total fruit weight than low flowering shoots. There were no significant differences in the average fruit weight and fruit diameter of the two flower loads. There were also no significant differences in fruit quality (fruit firmness, colour and TSS) between the two flower loads (data not presented).

Reproductive development and flowering.

Flowers were already present in buds collected on 21 December 2004, the earliest collection date (Fig. 1a). Full bloom lasted for about 2 weeks from 31 October 2005 until 14 November 2005 (Fig. 2). It gradually increased until 4 November 2005 when 28% of flowers were in full bloom and then it decreased until 14 November 2005. 71% of the flowers on a 30-60 cm one-year-old shoot were borne on the terminal quadrant of the shoot (Fig. 3). The second quadrant of the shoot borne 25% of the flowers and the third quadrant only 4%. The fourth quadrant had only vegetative buds.

Discussion

Knowledge of the reproductive and vegetative phenology of ‘Triumph’ persimmon under South African conditions is needed in order to address problems like poor fruit set and alternate bearing. This is because tree training and pruning strategies are dependent on knowledge of the tree’s phenology. This led to the questions: what type of shoot does the ‘Triumph’ persimmon tree bears its fruit on and what type of shoot produces the best quality fruit?

As evident from our data, the persimmon is quite a vigorous grower (Table 3). This vigour seems to be necessary in order to attain high yields. According to our findings, producers should aim to maximise the number of longer (30-60 cm) one-year-old shoots on ‘Triumph’ persimmon trees in order to produce the maximum possible fruit load (Table 1 & 2). Shorter one-year-old shoots are less prone to bear fruit, as the potential bearing positions become less. Shoots that were 0-10 cm long bore no fruits, because there were almost no flowers. These shoots often die back during winter (personal observation). Buban and Faust (1982) found that low vegetative growth lowered the number of flowers within the inflorescence in apples. The higher number of new laterals developing on the longer one-year-old shoots created more possible bearing positions and thus a greater potential crop load in the current season. The need for vigorous shoots has to be taken into account when considering planting densities and pruning strategies.

One-year-old shoots with heavier flower loads were significantly thicker than shoots with low flower loads (Table 4). These shoots possibly derived their greater diameter from positional effects within the canopy or on the branch that benefited them in terms of assimilate allocation. The thicker one-year-old shoots tended to have low fruit set percentages in comparison to the thinner one-year-old shoots, but produced more fruit due to higher flower numbers. Lauri et al. (1996), suggest that, within certain limits, vegetative growth enhances the flowering and fruit-setting process in apple.

Fruit borne on longer (30-60 cm) bearing units were less firm, more orange and had higher total sugar levels than fruit borne on short (<10 cm) shoots on the harvest date (Table 3). These results indicate that the fruits on longer shoots were more mature. Differences in ripening may be due to earlier full bloom on longer shoots. However, this does not seem to be the case (personal observation).

Pruning strategies must be aimed to obtain good re-growth in order to produce good quality shoots that will produce the highest possible crop load with the best fruit quality. Thus, if trees become too complex or if too high crop loads are left on the trees yield will be influenced negatively. In agreement with previous observations (Mowat and George, 1994), almost 75% of the fruit are borne on the most distal quadrant of bearing shoots (Fig. 3). It is important to keep this in mind when it comes to winter pruning. If these shoots are cut back heavily in winter potential fruit will be lost (Kitagawa and Glucina, 1984; Hasegawa et al., 1991).

Bearing in mind that persimmon trees produce most fruit on long, vigorous one-year-old shoots, we have to determine whether bending before bud break could be used to overcome apical dominance and increase the number of flowering shoots. Ito et al. (2004) showed that bending of Japanese pear shoots decreased the indole-3-acetic acid (IAA) concentration in lateral buds, but increased that of cytokinin. He postulated that these hormonal changes might enhance flower development. Almost no significant differences were found in vegetative and reproductive growth between vertical and horizontal shoots in this trial (Table 1, 2). At Vyeboom (Table 2) vertical shoots even had a higher number of new laterals than horizontal shoots. In contrast, Naor et al. (2003) found that bud break on horizontally positioned apple trees were more than twice that on vertically positioned trees. A possible explanation for our results could be that we used shoots that were growing horizontally or upright. Bending upright shoots to the horizontal position could have an effect on the hormonal balances in the shoot not occurring in shoots growing horizontally.

Flowers were present in the primordia on 21 December 2004 (Fig. 1a). This means that flower initiation must have occurred within about 11 weeks after bud break. Girdling during the flower initiation stage is used to increase reproductive development in many fruit species (Goren et al., 2004). Thus, girdling during spring of a heavy cropping “on” year may overcome the alternate cropping behavior of persimmons increasing return bloom. However, since persimmon bear most fruit on long, vigorous shoots that may continue to grow until much later in the season, girdling may be less effective than in “spur” bearers such as apple.

‘Triumph’ persimmon set fruit through parthenogenesis (Blumenfeld, 1981). Exogenous application of GA_3 promotes fruit set and parthenocarpic fruit development of persimmon (Sugiyama and Yamaki, 1994; Krisanapook et al., 1997). The effective flowering period for ‘Triumph’ persimmon under South African conditions appears to be more or less 14 days (Fig. 2) and GA_3 sprays need to be applied within the full bloom period. Normally GA_3 is applied at 30% full bloom and again at 70% full bloom. We can see from the full bloom distribution results that 30% full bloom occurs only two to four days after the first flowers in full bloom were observed and 70% full bloom seven days later. Thus it is of great importance to closely follow flower development in order to get the timing of GA_3 applications right.

Conclusion

Actions aimed at ensuring a good yield of high quality ‘Triumph’ fruit should ensure the presence of good quality bearing wood on the tree. This would be one-year-old shoots that are longer than 30 cm. These shoots can be produced by applying appropriate shoot thinning actions in the winter thus preventing over cropping. The need for relatively vigorous growth in order to produce sufficient bearing wood has to be considered when deciding on planting densities and training systems. It should be also taken into account that ‘Triumph’ initiate flowers distally on one-year-old shoots when it comes to shoot thinning.

Flower initiation seems to occur shortly after shoot elongation has ended. However, since flower initiation will take place later on longer shoots compared to shorter shoots, girdling to improve flower initiation may be less effective in persimmon. Lastly producers must bear in mind that 30% full bloom occurs already two to four days after the first flowers are in full bloom when it comes to GA_3 applications for fruit set.

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Table 1. The effect of shoot length and orientation on bud break, flowering and fruiting on one-year-old shoots of 3-year-old 'Triumph' persimmon trees in Sonkwasdrif (2004-2005). Means were separated by LSD (5%).

	Number of buds	Number of new shoots	Number of flowering shoots	Flowers / flowering shoot	Total flower number	Total fruit number
Shoot length						
0-10 cm	7.5 c[z]	0.3 c	0.0 b	.	0.0 b	0.0 b
10-30 cm	10.5 b	2.4 b	0.3 b	2.7 b	0.8 b	0.1 b
30-60 cm	16.9 a	10.1 a	4.1 a	4.9 a	21.7 a	1.0 a
Shoot orientation						
Horizontal	11.0 b	4.0	1.4	4.7	6.8	0.5
Vertical	12.3 a	4.4	1.5	4.2	8.3	0.3
			Pr>F			
Length	<0.0001	<0.0001	<0.0001	0.0399	<0.0001	0.0016
Orientation	0.0389	0.3926	0.8655	0.9698	0.5934	0.3758
Orientation*Length	0.1277	0.6603	0.8332	0.3900	0.8965	0.1853

[z] treatments with different letters differ significantly at $p<0.05$

Table 2. The effect of shoot length and orientation on bud break, flowering and fruiting on one-year-old shoots of 6-year-old 'Triumph' persimmon trees in Vyeboom (2004-2005). Means were separated by LSD (5%).

	Number of buds	Number of new shoots	Number of flowering shoots	Flowers / flowering shoot	Total flower number	Total fruit number
Shoot length						
0-10 cm	7.4 c[z]	0.5 c	0.0 b	.	0.0 b	0.0 b
10-30 cm	9.6 b	1.7 b	0.1 b	1.0 b	0.1 b	0.0 b
30-60 cm	13.0 a	6.2 a	1.8 a	3.0 a	6.2 a	0.5 a
Shoot orientation						
Horizontal	9.7	2.4b	0.8	3.3	2.7	0.2
Vertical	10.2	3.2 a	0.5	2.1	1.6	0.1
			Pr>F			
Length	<0.0001	<0.0001	<0.0001	0.0459	<0.0001	0.0042
Orientation	0.1861	0.0443	0.4625	0.2585	0.3817	0.3739
Orientation*Length	0.2816	0.1555	0.3959	0.6189	0.1219	0.2586

[z] treatments with different letters differ significantly at p<0.05

Table 3. Effect of shoot length on vegetative growth and fruit quality on one-year-old shoots of three-year-old 'Triumph' persimmon trees. Means were separated by LSD (5%) at Sonkwasdrif (2004-2005).

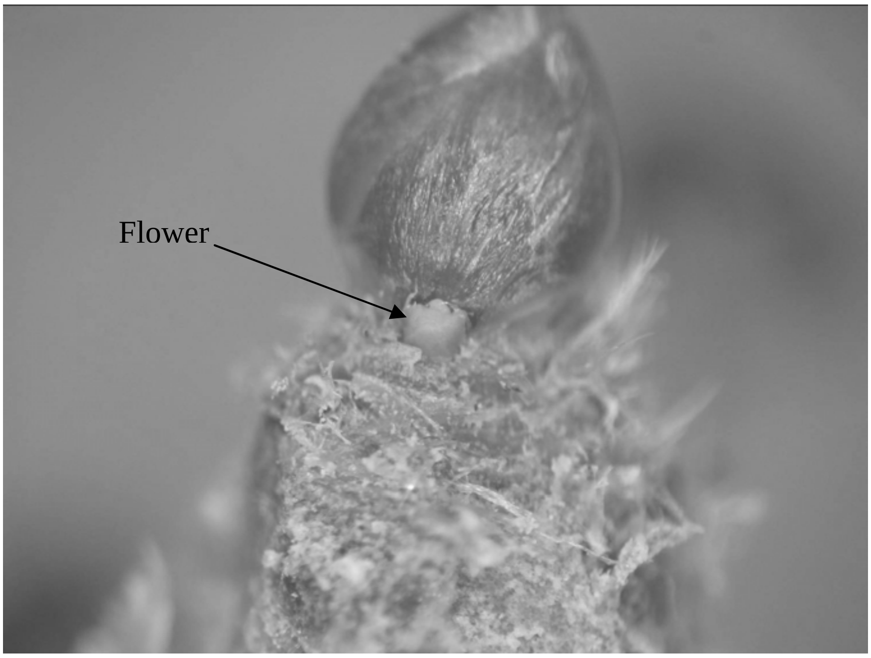
	Number of new shoots	Total vegetative growth (cm)	Average length of new shoots (cm)	Fruit diameter (cm)	Fruit firmness (kg)	Colour chart	Hue (º)	TSS (°Brix)
Shoot length								
0-10 cm	4.9 c[z]	114 c	24.3	6.08	8.9 a	5.1	71.8 a	21.9 b
10-30 cm	9.8 b	223 b	22.9	6.06	8.1 ab	5.4	69.5 b	23.0 a
30-60 cm	20.0 a	413 a	21.0	6.20	7.5 b	5.4	67.5 c	23.3 a
Pr>F	<0.0001	<0.0001	0.5144	0.7052	0.0866	0.5431	0.0002	0.0037

[z] treatments with different letters differ significantly at $p<0.05$

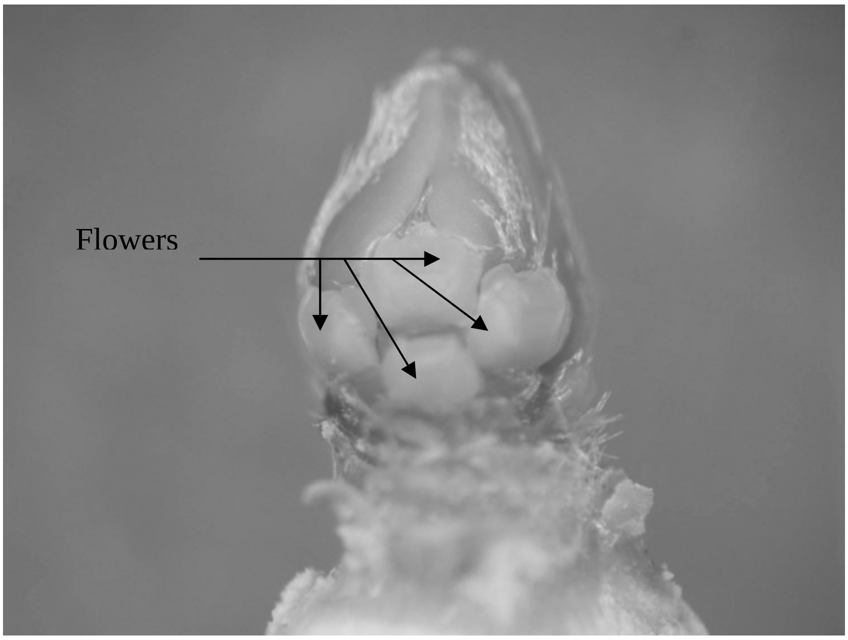
Table 4. Vegetative growth and fruit quality on ± 30 cm one-year-old 'Triumph' persimmon shoots differing in flower load. Means were separated by LSD (5%) at Sonkwasdrif (2004-2005).

	Shoot diameter (cm)	Number of new shoots	Total vegetative growth (cm)	Average length of new shoots (cm)	Total flower number	Total fruit number	Fruit set %	Average fruit weight (g)	Total fruit weight per shoot (g)
Flower load									
Low	1.34 b[z]	5.1 b	146.4 b	26.3	5.4 b	2.9 b	70.3 a	98.5	286 b
Heavy	1.78 a	11.2 a	290.0 a	27.4	35.2 a	7.9 a	23.2 b	97.3	737 a
Pr>F	0.0359	0.0045	0.0118	0.8076	0.0009	0.0444	0.0005	0.8726	0.0319

[z] treatments with different letters differ significantly at $p<0.05$



a)



b)

Fig. 1. Flowers present in reproductive buds of persimmon shoots (±30 cm) on a) 21 December 2004 (early stages of floral development) and b) 29 September 2005 (2 weeks before bud break).

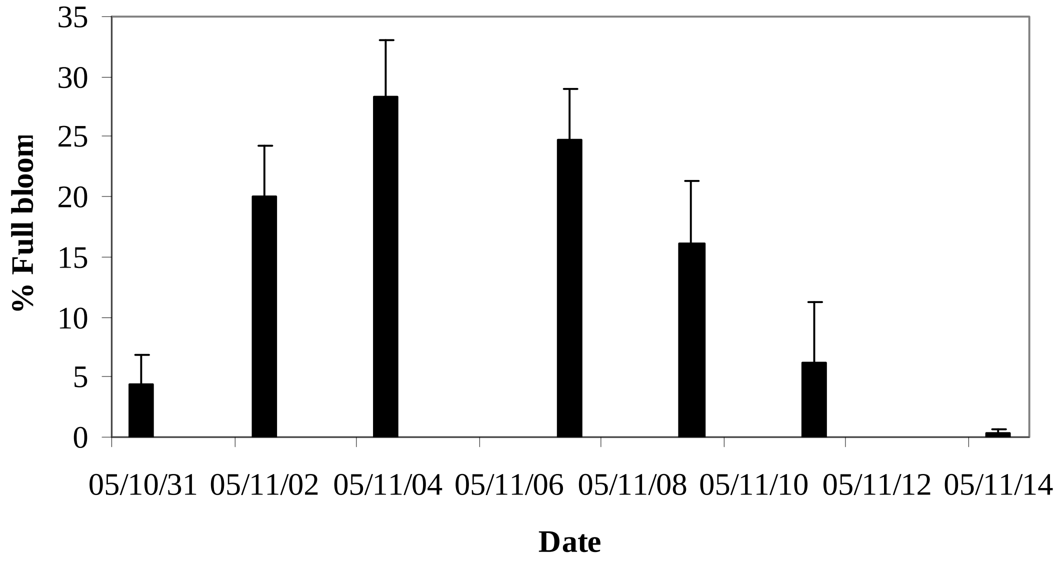


Fig. 2. Progression of flowering during spring 2005 on one-year-old ‘Triumph persimmon shoots.

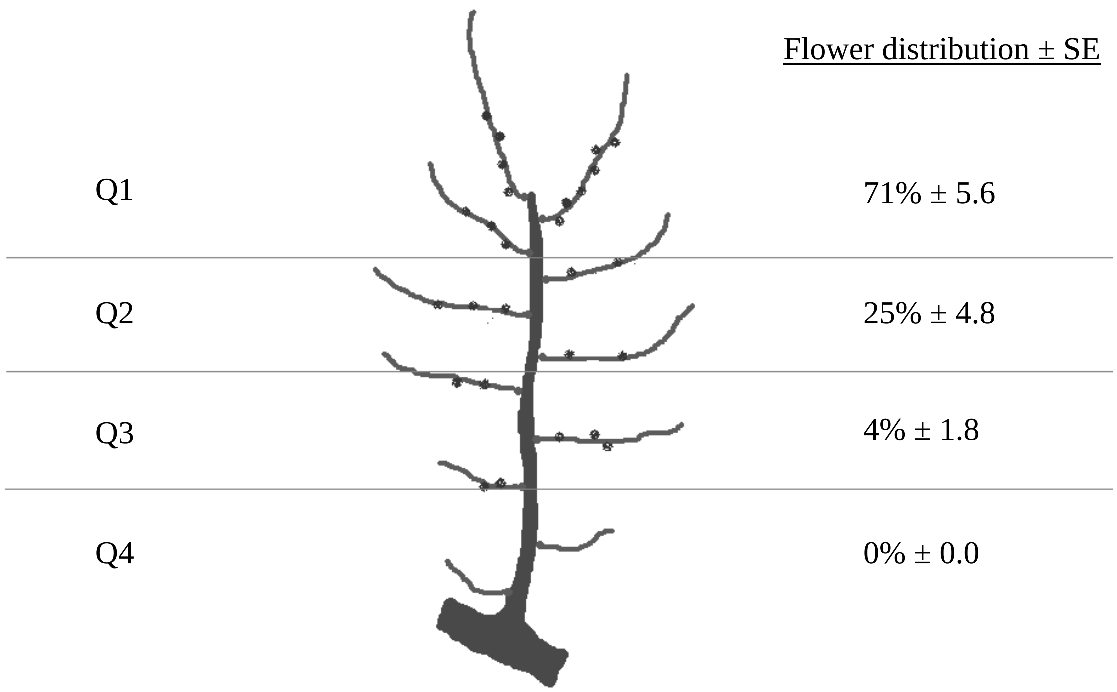


Fig. 3. Flower distribution on one-year-old (30-60 cm) shoots of ‘Triumph’ persimmon presented as the percentage of the total flowers on the shoot per quadrant.

PAPER 2:

IMPROVING FRUIT SET AND YIELD IN 'TRIUMPH' PERSIMMON (*Diospyros kaki* L.) WITH GA_3, GIRDLING OR SCORING

Abstract.

Obtaining regular high yields is a main goal of fruit growing. An increase in yield may result from either an increase in flowers that set fruit, more fruit units or from larger fruit (or a combination thereof). Experiments were conducted to determine the efficacy of gibberellic acid (GA_3) and scoring or girdling during full bloom (FB) to increase fruit set and yield in 'Triumph' persimmon. Different GA_3 concentrations (20 mg·L^{-1} and 40 mg·L^{-1}) were evaluated. GA_3 applications and scoring/girdling were applied at 30% FB or 30 and 70% FB. While GA_3 treatments were ineffective, scoring increased fruit set and yields in young orchards (< 5-year-old) by up to three times. However, fruit size was reduced. In more mature orchards (> 5-year-old), scoring or girdling in combination with GA_3 applications at 30 and 70% FB increased yield by an average of 16 tons (45%) compared to GA_3 treatment on its own. This increase in yield did not affect fruit size. Girdling and scoring were equally effective in increasing yield. Based on these data, guidelines to manage fruit set can be developed for the South African persimmon industry. However, these guidelines will also need to entail pruning and thinning strategies to prevent alternate bearing.

High yields depend primarily on adequate flowering and subsequent fruit set (Albrigo and Saúco, 2004). Fruit set represents a critical stage in the production cycle of many tree crops (Martinez-Cortina and Sanz, 1991). Fruit drop after flowering is an important problem in persimmon (Kitagawa and Glucina, 1984). Many physiological and biochemical steps, under hormonal control, regulate the process of abscission in apple (Pandita & Jindal, 2004). In apple, fruit abscission during early fruit development is due to a correlatively driven abscission process (Bangerth, 2000) caused by other adjacent fruit or vigorously growing shoot tips, which are strong sources of gibberellic acid (GA)-stimulated auxin (IAA) signals (Callejas and Bangerth, 1997). The same may apply to persimmon. George et al. (1994) suggested that fruit abscission in persimmon is triggered by the prevention of assimilate transport to fruits.

'Triumph' persimmon trees set fruit parthenocarpicaly (Blumenfeld, 1981). Of the various ways to improve parthenocarpic fruit set, gibberellins (GA_3) application and girdling during flowering are probably the most effective. GA_3 application induces parthenocarpic fruit set in a variety of fruit species, i.e. peach (Stutte and Gage, 1990), 'Clementine' mandarin (Talon et al., 1992), apple (Bangerth and Schröder, 1994), persimmon (Sugiyama and Yamaki, 1994) and pear (Deckers and Schoofs, 2002). Exogenous applications of GA_3 increase GA concentrations in the pericarp of fruit which may have several functions; (i) reducing the ABA concentration in the ovule, (ii) re-initiating cell division, (iii) stimulating cell growth and (iv) increasing sink activity (Bangerth, 2004). All of these may improve parthenocarpic fruit set.

Trunk girdling, i.e. the removal of a strip of bark (phloem and cambium) around the trunk, during flowering has been shown to be an effective technique to improve fruit set in persimmons (Hasegawa et al., 2003). The mechanism through which girdling acts is poorly understood although changes in translocation and accumulation of carbohydrates as a result of girdling have been reported in citrus (Wallerstein et al., 1973). Carbohydrate limitation is one of the factors reducing fruit set in citrus (Goldschmidt, 1999). The downward flow of photosynthetic products is blocked at the girdle, while water and mineral transport from the roots to the canopy are not directly affected. Hence, the effect of girdling on fruit set may be a result of increased supply of carbohydrates to the reproductive organs (Goren et al., 2004). There is also evidence of changes in plant growth regulator concentrations following girdling (Wallerstein et al., 1973; Goren et al., 2004). A possible role of IAA in apical dominance is to control the distribution and metabolism of cytokinin (CK) (Bubán, 2000). In apple, the disruption of the basipetal transport of IAA leads to a rapid, short-term increase in xylem-transported CK, presumably from the roots (Bangerth et al., 2000). This increase in CK may increase the sink activity of fruits, thereby increasing fruit set.

The objectives of the experiments reported here were to evaluate the effect of, 1) GA_3 concentration and number of applications (30% FB or 30 and 70% FB), 2) scoring or girdling and 3) interactions between GA_3 and girdling/scoring on fruit set and yield in 'Triumph' persimmon. The ultimate objective of this work is to develop guidelines for South African producers to improve fruit set of 'Triumph' persimmon.

Materials and Methods

2004/2005.

Experiment 1: The experiments were conducted at Sonkwasdrif (latitude: 33°20'S, longitude: 18°59'E) in the Western Cape Province (Mediterranean climate) of South Africa. The trees on *Diospyros virginiana* seedling rootstock were planted in 2001 at a spacing of 3.5 x 1.5 m. The effects of GA_3 (Valent BioSciences Co., Libertyville, IL., USA), scoring with girdling pliers (Optima Products, Paarl, South Africa) developed for use on citrus and treatment combinations on fruit set, yield and fruit quality were evaluated. GA_3 was applied at 20 $mg \cdot L^{-1}$ (30% FB or 30 and 70% FB) or 40 $mg \cdot L^{-1}$ (30% FB). Scoring entailed making an incision through the phloem and cambium in a complete circle around the trunk 10 cm above the graft union. This was done at 30% full bloom (FB). GA_3 (20 $mg \cdot L^{-1}$, 30 & 70% FB) and scoring (30% FB) were also combined as a treatment. Thirty and 70% FB occurred on 25 and 31 October 2004 respectively. Treatments were randomised in 10 blocks in a single row with one tree per plot with guard trees between plots. GA_3 were applied on windless mornings with a truck mounted motorized sprayer until drip off. A nonionic surfactant, Break-Thru, a.i. polether-polymethylsiloxane-copolymer (Western Farm Service, Inc., Fresno, CA., USA) at was added (0.5 ml L^{-1}) to spray treatments in all experiments reported in this paper.

Fruit set and fruit drop. To determine fruit set, a single ±30 cm, one-year-old shoot per tree was randomly selected before flowering. Remaining peduncles and fruit were counted on 1 December 2004 to assess fruit set. Peduncles persist on the tree for three months or more after flower abscission allowing the determination of initial flower number at this late date. Fruit were counted again on 10 February 2005 to determine fruit drop.

Fruit quality at harvest. All the fruit per tree were harvested on 10 May 2005 and weighed to determine yield in kg per tree and this was converted to ton per ha. A 20 fruit sample per plot was used to determine fruit diameter (measured by electronic calliper), average fruit mass and flesh firmness (determined on pared, opposite cheeks of the fruit using a GÜSS fruit texture analyser with an 11 mm tip). Fruit colour was assessed using a sweet persimmon colour chart (Sweet Persimmon Growers Trust, South Africa) (values 1-8 where 8 = red/orange and 1 = green) and a Minolta chroma meter (Model CR-400, Minolta Co. Ltd., Tokyo, Japan). Slices cut from each side of the fruit were pooled juiced and TSS was measured using a refractometer (PR32, ATAGO Co. Ltd., Tokyo, Japan). The total fruit mass per tree was divided by the average fruit mass of the 20-fruit sample to estimate fruit number per tree.

Experiment 2: A trial was conducted at Jagersbos, Greyton (latitude: 34°8'S, longitude: 19°83'E) with the initial objective to determine the effect of yield on return bloom in a full bearing orchard. Trees on *D. virginiana* seedling rootstock were planted in 2001 at a spacing of 5 x 2.5 m. GA_3 (20 mg·L^{-1}) at 30% FB (4 November 2004) and 70% FB (9 November 2004) in combination with scoring at 30% FB were applied with the objective to obtain the largest possible yield. Trees were then thinned to different yields using two fruit thinning and two shoot thinning treatments. These four treatments were also repeated on trees that did not receive GA_3 and scoring applications. The resultant eight treatments were randomised in 10 blocks with single tree plots, guard trees between trees and guard rows between treatment rows. GA_3 applications were made as mentioned before. Fruit set was determined on a single one-year-old shoot per tree by counting flower peduncles and fruit on 25 December 2004 and again on 8 February 2005. Unfortunately some of the tagged shoots were pruned during the summer. Therefore yield and return bloom could not be assessed. However we could still compare fruit set on trees that were scored and received GA_3 to fruit set on control trees that did not receive any fruit set treatments.

2005/2006.

Experiments 3 and 4: The effect of GA_3 and scoring on fruit set and yield were further evaluated in two young orchards at Simondium (latitude: 33°3'S, longitude: 19°9'E) and Sonkwasdrif (latitude: 33°20'S, longitude: 18°59') in the Western Cape Province (Mediterranean climate) of South Africa. In both orchards *D. virginiana* seedling rootstock was used. Trees at Simondium were planted in 2002 at a spacing of 5 x 2 m and at Sonkwasdrif in 2001 at a spacing of 3.5 x 1.5 m. GA_3 was applied as in 2004/2005 at 20 or 40 mg·L^{-1} on 30% FB or 30% and 70% FB on 26 October 2005 and 1 November 2005 at Sonkwasdrif and on 25 and 29 October 2005 at Simondium. Scoring was done with girdling pliers 10 cm above graft union at 30% FB. Treatments were randomised in 15 blocks with one tree per plot with a guard tree between plots. Fruit set was determined by counting flower stems and fruit on 13 December 2005 and again on 14 February 2006 on three one-year-old shoots per tree. Yield as well as total number of fruit per tree was determined as previously described.

Experiment 5: The use of scoring and girdling to increase fruit set and yield were further evaluated in a full bearing orchard at Vyeboom, Villiersdorp (latitude: 34°3'S, longitude: 19°9'E). Trees on *D. virginiana* seedling rootstock were planted in 1999 at a spacing of 5 x 2 m. The main objective of this experiment was to determine whether treatments could improve yield compared to the recommended commercial standard application (20 mg·L^{-1} GA_3 at 30 and 70% FB) and therefore no untreated control was included. GA_3 (20 mg·L^{-1}) was applied at 30% FB (2 November 2005) and again at 70% FB (9 November 2005) on trees of five treatments. Trees of two of these five treatments were scored with girdling pliers at either 30% FB, or 30% and 70% FB. Another two of the treatments were girdled with a tree saw (Felco600, Felco SA, Switzerland) also at either 30% FB, or 30% and 70% FB. These scoring and girdling applications were repeated in a further four treatments that did not receive GA_3. The resultant nine treatments were randomised in 15 blocks with one tree per plot and guard trees between plots. Guard rows were left between treatment rows. Fruit set was determined by counting flower peduncles and fruit on 14 December 2005 and again on 13 February 2006 on three one-year-old shoots per tree. Yield as well as total number of fruit per tree was determined as previously described.

Statistical analysis. Data of all experiments were analysed with the General Linear Models (GLM) procedure in the SAS (Statistical Analysis System) computer program (SAS Enterprise Guide 3.0; SAS Institute, 2004, Cary, NC., USA). Means were separated by LSD (5%). Initial flower number was used as covariate to amend for differences in flower number between treatments and adjusted means are used where applicable. Single degree of freedom, orthogonal, polynomial contrasts were also used.

Results

2004/2005.

Experiment 1 (Table 1): Although scoring significantly increased fruit set as assessed in December and yield compared to GA_3 treatments, GA_3 applications and scoring did not differ significantly from the control. Final estimated fruit numbers per tree did not differ significantly between treatments. GA_3 (30 and 70% FB) in combination with scoring (30% FB) decreased fruit size compared to the control, scoring on its own and GA_3 (20 mg·L^{-1}) applied once at 30% FB. Treatment effects on TSS, fruit firmness and colour were not significant (data not presented).

Experiment 2 (Table 2): The combination of GA_3 (30% & 70% FB) and scoring (30% FB) significantly improved fruit set and reduced fruit drop between December and February compared to the unsprayed, unscored control.

2005/2006.

Experiments 3 and 4: Scoring consistently improved fruit set, number of fruit per tree and yield per hectare compared to the control and GA_3 treatments at both Sonkwasdrif and Simondium (Table 3, 4). At Simondium, GA_3 at 40mg·L^{-1} significantly increased fruit retention until February compared to GA_3 at 20 mg·L^{-1} ($p = 0.0496$). All treatments except for GA_3 at 40 mg·L^{-1} applied at 30% FB significantly decreased fruit size compared to the control (Table 3). However, only scoring significantly increased fruit numbers compared to the control. GA_3 applied twice significantly reduced fruit size compared to one application even though fruit numbers and yield were not affected ($p = 0.0027$)(Table 3).

At Sonkwasdrif, scoring and GA_3 applied twice at 40 mg·L^{-1} reduced fruit size compared to the control (Table 4). However, the GA_3 application had no effect on fruit numbers. Scoring also decreased fruit size compared to GA_3 at 20 mg·L^{-1} applied once or twice and GA_3 at 40 mg·L^{-1} applied once.

Experiment 5 (Table 5): Compared to the industry standard of 20 mg·L^{-1} GA_3 at 30% and 70% FB, the rest of the treatments significantly increased fruit set, estimated fruit numbers per tree and yield. GA_3 in combination with girdling or scoring increased fruit set and the number of fruit per tree compared to girdling/scoring on its own, but yield per hectare was not increased due to a reduction in fruit size. Where GA_3 was not applied, girdling or scoring twice significantly increased fruit set compared to girdling or scoring only at 30% FB. However, when trees also received GA_3, girdling and scoring twice had no additional effect on fruit set. Girdling/scoring twice did not affect yield and fruit size compared to girdling/scoring once. Scoring significantly increased fruit set compared to girdling. However, this did not result in a significant increase in final fruit numbers or yield. Girdling and scoring with or without GA_3 application showed significantly higher fruit drop between December and February compared to the industry standard. Despite a 40-43% increase in fruit numbers and yield, girdling or scoring alone or in combination with GA_3 did not decrease average fruit mass compared to the industry standard treatment.

Discussion

Young orchards.

In the 2004-2005 season, scoring nearly doubled fruit set compared to the untreated control resulting in a comparative increase in the number of fruit per tree and yield (Table 1). However, these differences were not statistically significant due to considerable between-tree variation. During the 2005/2006 season (Table 3, 4), scoring consistently increased fruit set and yield. Girdling has been shown to be an effective technique to improve fruit set in persimmon (Hasegawa et al., 2003). However, the increased fruit load of girdled trees may reduce fruit size (Table 3, 4) and vegetative growth (not measured). The negative correlation between fruit number and fruit size is well established for various fruit species (Kitagawa and Glucina, 1984; Crisosto et al., 1997). Any treatment that increases the number of fruit per tree potentially decreases fruit size by reducing carbohydrate availability and thereby decreasing cell division and cell growth. Besides assimilate allocation, there is also a considerable negative correlative effect of the number and growth rate of adjacent fruits on individual fruit size (Bangerth, 2005). It has to be kept in mind that heavy cropping may be undesirable in young orchards that still need to fill their allotted space. Sufficient vegetative growth and some level of cropping may be obtained in young orchards by a combination of winter pruning and scoring during anthesis.

Reasons for the ineffectiveness of GA_3 applications to improve fruit set and yield in young ‘Triumph’ persimmon trees (Table 1, 3, 4) are uncertain. However, despite this general ineffectiveness of GA_3, it appears that higher GA_3 rates (two vs. one application at Simondium and two applications at 40 $mg \cdot L^{-1}$ at Sonkwasdrif) decreased average fruit mass (Tables 3, 4). In general, GA_3 sprays decreased fruit size although it did not increase yield and the number of fruit per tree compared to the control (Table 3). Gross et al. (1984) found that the application of GA_3 10 days prior to harvest leads to the cessation of persimmon fruit growth for approximately 2 weeks whereafter it resumes at the same rate that preceeded treatment. It is uncertain whether GA_3 applied at full bloom may have a similar effect on fruit growth. Another possible explanation for the negative effect of GA_3 on fruit size may lie in the positive effect of GA_3 on shoot growth. Gibberellins are generally known for their marked effect on elongation of shoots (Salisbury and Ross, 1992). Unfortunately, shoot growth was not measured.

Full bearing orchards.

The average yield of ‘Triumph’ persimmon in Israel is 30 tons per hectare (Llácer and Badenes, 2002). Scoring or girdling, with or without GA_3 applications, increased fruit numbers and yield by 40-43% in comparison to the 232 fruits per tree and 35 t ha^{-1} of the industry standard treatment (Table 5). Previously, Hasegawa et al. (2003) also found trunk girdling of persimmon to increase yield. Interestingly, the increase in fruit numbers and yield with girdling or scoring without GA_3 application was not associated with a decrease in average fruit mass (Table 5). This could be due to changes in carbohydrate partitioning in response to girdling/scoring favouring fruit growth. Due to higher fruit numbers per tree, girdling or scoring in combination with GA_3 did, however, reduce fruit size compared to only girdling or scoring (Table 5).

The data presented here provide producers with a set of tools to increase fruit set and production of ‘Triumph’ persimmon. The overall lower fruit drop of the industry standard compared to other treatments is most probably due to its lower initial fruit set (Table 5). Increasing fruit set and yield of ‘Triumph’ persimmon may result in the onset of alternate bearing by reducing vegetative growth and, thereby reducing bearing positions for the following season. Persimmons have a natural tendency to set heavy crops of small fruit followed by light crops of large fruit (Collins and George, 1997). Unfortunately, we did not measure shoot growth, but differences were not observed (personal observation). Alternate bearing can possibly be addressed by shoot pruning during winter and during fruit development or by fruit thinning in the on-year (Monselise and Goldschmidt, 1982). When it comes to pruning actions, it is important to remember that the ‘Triumph’ persimmon bears its fruit terminally on long (>30 cm) one-year-old shoots (Paper 1). Pruning and thinning strategies to regulate yield and to ensure the formation of sufficient bearing wood should form part of further research.

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Table 1. The effect of GA_3 application and scoring on fruit set, yield and fruit quality on 3-year-old ‘Triumph’ persimmon trees at Sonkwasdrif in 2004/2005. Means are separated by LSD (5%).

Treatments	Fruit set % December [x]	Fruit set % February [x]	Estimated number of fruit / tree	Yield (t ha^{-1})	Fruit diameter (mm)	Average fruit mass (g)
Control	21 ab[z]	10[ns]	15[ns]	3.4[ns]	61.1 a	113 a
GA_3 20 mg·L^{-1} (30% FB[y])	18 b	12	18	3.9	59.8 a	109 a
GA_3 20 mg·L^{-1} (30% & 70% FB)	16 b	8	19	3.6	59.3 ab	110 a
GA_3 40 mg·L^{-1} (30% FB)	23 ab	17	22	4.2	58.3 ab	103 ab
Scoring (30% FB)	41 a	22	33	7.2	61.1 a	113 a
GA_3 20 mg·L^{-1} (30% & 70% FB) & Scoring (30% FB)	41 a	24	34	6.0	56.2b	86 b
			Pr > F			
Treatment	0.0905	0.2739	0.1935	0.2665	0.0288	0.0140
Control vs Treatments	0.4772	0.2855	0.1468	0.2208	0.1203	0.1846
GA_3 vs Scoring	0.0206	0.1389	0.0910	0.0449	0.0808	0.1995
GA_3 (30% FB) vs GA_3 (30% & 70% FB)	0.6281	0.3597	0.7093	0.7987	0.9253	0.9799
GA_3 20 mg·L^{-1} vs GA_3 40 mg·L^{-1}	0.5588	0.4057	0.9434	0.9858	0.4743	0.6529
GA_3 or Scoring vs GA_3 & Scoring	0.0659	0.1631	0.1310	0.3711	0.0100	0.0012

[z] treatments with different letters differ significantly at $p < 0.05$

[y] full bloom

[x] % of initial number of flowers

[ns] not significant

48

Table 2. Effect of GA3 application (20 mg·L^{-1}, 30 and 70% full bloom) and scoring on fruit retention on five-year-old 'Triumph' persimmon trees at Greyton in 2004/2005. Means, adjusted for flower number, are separated by LSD (5%).

Treatments	Fruit set % December [y]	Fruit set % February [y]	Fruit drop % Dec. – Feb.
Control	75 b[z]	26 b	66.9 b
GA_3 & Scoring	90 a	80 a	12.6 a
	Pr > F		
Treatment	0.0067	<0.0001	<0.0001
Flower number	0.0001	<0.0001	-

[z] treatments with different letters differ significantly at $p < 0.05$

[y] % of initial number of flowers

Table 3. Effect of number and concentration of GA_3 application and scoring on fruit set and yield of 3-year-old 'Triumph' persimmon trees at Simondium in 2005/2006. Means, adjusted for flower number, are separated by LSD (5%).

Treatments	Fruit set % December [x]	Fruit set % February [x]	Estimated number of fruit / tree	Yield (t ha^{-1})	Average fruit mass (g)
Control	12.3 b[z]	11.8 bc	29 b	5.2 b	179 a
GA_3 20 mg·L^{-1} (30% FB[y])	11.6 b	10.1 c	37 b	5.7 b	162 bc
GA_3 40 mg·L^{-1} (30% FB)	15.6 b	15.6 bc	46 b	7.6 b	169 ab
GA_3 20 mg·L^{-1} (30% & 70% FB)	12.2 b	11.9 bc	31 b	4.7 b	154 c
GA_3 40 mg·L^{-1} (30% & 70% FB)	20.9 b	20.7 b	50 b	7.3 b	150 c
Scoring (30% FB)	37.7 a	34.7 a	100 a	15.8 a	157 bc
		Pr > F			
Treatment	<0.0001	<0.0001	<0.0001	<0.0001	0.0001
Flower number	0.0227	0.0234	-	-	-
Control vs GA_3	0.4848	0.4894	0.2112	0.4652	<0.0001
GA_3 vs Scoring	<0.0001	<0.0001	<0.0001	<0.0001	0.8041
Control vs Scoring	<0.0001	<0.0001	<0.0001	<0.0001	0.0008
A: GA_3 (30% FB) vs GA_3 (30% & 70% FB)	0.4114	0.3380	0.9223	0.6134	0.0027
B: GA_3 20 mg·L^{-1} vs GA_3 40 mg·L^{-1}	0.0835	0.0496	0.1055	0.0980	0.7644
A * B	0.5228	0.6340	0.5307	0.7852	0.2214

[z] treatments with different letters differ significantly at $p < 0.05$

[y] full bloom

[x] % of initial number of flowers

50

Table 4. Effect of number and concentration of GA_3 application and scoring on fruit set and yield on 4-year-old 'Triumph' persimmon trees at Sonkwasdrif in 2005/2006. Means, adjusted for flower number, are separated by LSD (5%).

Treatments	Fruit set % December [x]	Fruit set % February [x]	Estimated number of fruit / tree	Yield (t ha^{-1})	Average fruit mass (g)
Control	19 b[z]	18 b	46 b	14.1 b	160 a
GA_3 20 $mg{\cdot}L^{-1}$ (30% FB[y])	15 b	15 b	49 b	13.7 b	156 ab
GA_3 40 $mg{\cdot}L^{-1}$ (30% FB)	20 b	17 b	40 b	10.5 b	143 ab
GA_3 20 $mg{\cdot}L^{-1}$ (30% & 70% FB)	15 b	15 b	48 b	12.4 b	144 ab
GA_3 40 $mg{\cdot}L^{-1}$ (30% & 70% FB)	17 b	17 b	48 b	12.8 b	142 bc
Scoring (30% FB)	43 a	42 a	146 a	34.1 a	126 c
		Pr > F			
Treatment	<0.0001	<0.0001	<0.0001	<0.0001	0.0034
Flower number	<0.0001	<0.0001	-	-	-
Control vs GA_3	0.7369	0.7227	0.9257	0.6256	0.0522
GA_3 vs Scoring	<0.0001	<0.0001	<0.0001	<0.0001	0.0034
Control vs Scoring	<0.0001	<0.0001	<0.0001	<0.0001	0.0002
A: GA_3 (30% FB) vs GA_3 (30% & 70% FB)	0.8077	0.9595	0.7455	0.8369	0.2839
B: GA_3 20 $mg{\cdot}L^{-1}$ vs GA_3 40 $mg{\cdot}L^{-1}$	0.4512	0.6285	0.6537	0.5673	0.2404
A * B	0.7365	0.8891	0.6408	0.4391	0.3455

[z] treatments with different letters differ significantly at $p < 0.05$

[y] full bloom

[x] % of initial number of flowers

51

Table 5. Effect of girdling or scoring on its own or in combination with GA3 application on fruit set, crop load and fruit size on 'Triumph' persimmon at Vyeboom. Means, adjusted for flower number, are separated by LSD (5%).

GA_3 (20 mg·L^{-1}, 30% & 70% FB)	Scoring/Girdling	Fruit set % December [x]	Fruit set % February [x]	Fruit drop % Dec. - Feb.	Estimated number of fruit / tree	Yield (t ha^{-1})	Average fruit mass (g)
Y (industry standard)	–	49 cd[z]	48 bc	2.5 b	232 c	35 b	153 ab
Y	Scoring (30% FB[y])	78 a	67 a	15.3 a	387 a	58 a	153 ab
Y	Girdling (30% FB)	59 bc	53 ab	10.2 ab	303 abc	46 ab	158 a
Y	Scoring (30% & 70% FB)	80 a	65 ab	19.4 a	354 ab	50 a	152 ab
Y	Girdling (30% & 70% FB)	61 bc	51 b	16.9 a	366 a	50 a	135 b
N	Scoring (30% FB)	50 cd	45 bc	10.2 ab	291 abc	48 ab	168 a
N	Girdling (30% FB)	38 d	36 c	11.5 ab	256 bc	45 ab	173 a
N	Scoring (30% & 70% FB)	67 ab	63 ab	10.0 ab	338 ab	54 a	164 a
N	Girdling (30% & 70% FB)	58 bc	55 ab	10.2 ab	293 abc	49 ab	172 a
		P > F					
Treatment		<0.0001	0.0005	0.1829	0.0384	0.1407	0.0144
Flower number		<0.0001	<0.0001	-	-	-	0.0116
Industry standard vs Rest		0.0158	0.2121	0.0174	0.0163	0.0070	0.4428
A: Girdling/Scoring & GA_3 vs Girdling/Scoring		<0.0001	0.0151	0.0900	0.0226	0.5883	0.0004
B: Girdling/Scoring once vs Girdling/Scoring twice		0.0034	0.0293	0.4231	0.2549	0.6307	0.1723
C: Girdling vs Scoring		<0.0001	0.0031	0.5997	0.1304	0.1422	0.9978
A * B		0.0160	0.0073	0.2907	0.5851	0.3498	0.3757
A * C		0.2255	0.4462	0.4244	0.9336	0.7261	0.2679
B * C		0.8115	0.9372	0.8987	0.3883	0.5171	0.3798
A * B * C		0.8430	0.9716	0.7493	0.2812	0.3456	0.2429

[z] treatments with different letters differ significantly at $p < 0.05$

[y] full bloom

[x] % of initial number of flowers

52

PAPER 3:

EXTENDING THE HARVEST PERIOD AND IMPROVING THE STORABILITY AND SHELF LIFE OF 'TRIUMPH' PERSIMMON (*Diospyros kaki* L.)

Abstract.

The commercial harvesting of 'Triumph' persimmon (*Diospyros kaki* L.) in South Africa occurs over a two to three week period. This short harvesting period puts pressure on producers and packing facilities, and shortens the marketing window of fruit. The primary objective of this study was to extend the harvest window of 'Triumph' persimmon by using scoring or plant growth regulators to advance or delay fruit ripening. The effect of treatments on fruit quality at harvest, after storage for three months at -0.5 °C and shelf life of 5 to 7 days at 15 °C were evaluated over two seasons. n-Propyl dihydrojasmonate (PDJ), aminoethoxyvinylglycine (AVG) and scoring generally did not affect fruit ripening and storability. 2-Cloroethyl phosphonic acid (ethephon) applied at 24 mg·L^{-1} four weeks before the first of two harvest dates advanced ripening. Gibberellic acid (GA_3) application at 50 (mg·L^{-1}), delayed fruit ripening and reduced fruit softening during storage and shelf life. 1-Methylcyclopropene (MCP) applied after harvest maintained fruit quality during cold storage and shelf life. Future research should evaluate combined treatments of ethephon with MCP or GA_3 to advance harvesting without negatively effecting storability of fruit.

The harvest season of the astringent persimmon 'Triumph' lasts only 2 to 3 weeks under South African conditions. 'Triumph' is the only commercially planted astringent cultivar locally. This short harvesting period puts pressure on producers and packing facilities, and shortens the marketing window of fruit. The marketing season can be extended to about 3 to 4 months by storage at -1 °C, in air or controlled atmospheres (CA) (Tsviling, 2003). The shelf life of 'Triumph' fruit is inversely proportional to storage period, the limiting factor being fruit softening (Ben-Arie and Guelfat-Rech, 1976). As prices tend to decrease with increasing volumes of fruit on the market, extending the harvest window, improving storability and increasing shelf life may increase net returns to producers by spreading the supply of fruit over a longer period.

In climacteric fruits such as persimmon, endogenous ethylene is suggested to play an important role during the ripening process. Various methods are used to advance or delay fruit ripening. These include the application of plant growth regulators (PGR's). Among the PGR's that delay ripening, gibberellic acid (GA_3), application 14 days before harvest, appears to be the most effective in persimmon (Ben-Arie et al., 1986). The immediate effect in the orchard after GA_3 application is the cessation of fruit growth, chlorophyll degradation and carotenoid biosynthesis (Gross et al., 1984). Ripening resumes after approximately two weeks, at a similar rate to non-treated fruit. The outcome is therefore a delay in fruit ripening and harvesting. GA_3 application 10 days prior to harvest also improves the keeping quality of persimmons after harvest (Kitagawa et al., 1966; Ben-Arie et al., 1986). Aminoethoxyvinylglycine (AVG) is another PGR that can be applied prior to harvest in order to delay ripening and possibly improve the storability and shelf life of fruit. AVG is a potent inhibitor of amino-cyclopropane-1-carboxylic acid (ACC) synthase activity, preventing the formation of ACC, the precursor of ethylene (McGlasson, 1985). AVG reduces fruit ethylene production and respiration in apples (Greene, 1996). Progression of ripening relates to the availability of ethylene, while the onset of ripening may be due to enhanced ethylene sensitivity (Lelievre et al., 1997). Inhibiting ethylene biosynthesis should therefore delay ripening and reduce loss of fruit quality in 'Triumph' persimmon (Greene, 1996; Ben-Arie et al., 1997). By delaying the harvesting of persimmon, AVG application may have the additional benefit of improving fruit size (Ben-Arie et al., 1997).

1-Methylcyclopropene (MCP) is a volatile structural analogue of ethylene that inhibits ethylene action and ethylene biosynthesis by binding irreversibly to ethylene receptor sites (Sisler and Serek 1997; Blankenship and Dole, 2003). MCP has received considerable interest in the post-harvest industry as a tool for blocking ethylene responses associated with fruit ripening and senescence (Warner et al., 2003). Tsviling et al. (2003) found that post-storage treatment with MCP doubled the shelf life of persimmon fruit, especially after extended storage of 3 to 4 months. Warner et al. (2003) demonstrated that MCP is consistently effective for retaining firmness and maintaining total soluble solids (TSS) during long term storage of apples. Although only applied after harvest, we also evaluated the effect of MCP on the storability and shelf life of 'Triumph' persimmon. Our reasoning was that, if effective in delaying ripening during shelf life, MCP treatment may allow the harvesting of 'Triumph' at a greater maturity, thereby delaying harvesting.

We evaluated the use of n-propyl dihydrojasmonate (PDJ), 2-cloroethyl phosphonic acid (ethephon) and scoring as treatments to advance fruit ripening. PDJ is a jasmonic acid derivative that is assumed to be more stable than the natural hormone. PDJ affects ethylene synthesis through stimulating ethylene-forming enzyme activity (Saniewski et al., 1987; Czapski and Saniewski, 1992). Therefore, it is thought that PDJ could enhance fruit ripening by regulating ethylene evolution (Gemma et al., 1997). Spray applications of PDJ 20 to 30 days prior to harvest promoted ripening of grapes as well as ‘Fuyu’ persimmon (Fujisawa et al., 1997). Ethephon is an ethylene generator that has been shown to enhance fruit maturity and increase total soluble solids in persimmon (Kim et al., 2004).

Scoring, i.e., an incision through the phloem and cambium in a complete circle around the trunk, blocks the downward flow of photosynthetic products at the girdle, thereby increasing the availability of assimilates to developing organs above the girdle (Ruiz et al., 2001; Goren et al., 2004). The increased availability of carbohydrates has been suggested to be responsible for the advancement in maturity in apples, pears (Dennis, 1968), olives (Lavee et al., 1983), nectarines (Day & DeJong, 1990; De Villiers, 1990) and persimmons (Hasegawa et al., 2003).

Here we report on the use of pre- and post-harvest treatments to delay (GA_3, AVG and MCP) or advance (PDJ, ethephon and scoring) the maturity of ‘Triumph’ persimmons. We also assessed the effect of treatments on storage potential and shelf life.

Materials and Methods

2004/2005

Plant material and experimental design: The experiment was conducted in a 6-year-old ‘Triumph’ persimmon (*Diospyros kaki* L.) orchard located in Bonnievale (latitude: 33°58’ S; longitude: 20°11’E) in the Western Cape Province (Mediterranean climate) of South Africa. Trees on *D. virginiana* seedling rootstock were planted at a spacing of 5 x 2.5 m. The following treatments were evaluated: 1) control, 2) 50 $mg \cdot L^{-1}$ GA_3 (Valent BioSciences Co., Libertyville, IL., USA) applied on 18 April 2005, 16 days before the first harvest, 3) 125 $mg \cdot L^{-1}$ AVG (Valent BioSciences Co., Libertyville, IL USA) applied 3 weeks before the first harvest (WBFH), 4) 200 $mg \cdot L^{-1}$ PDJ (Valent BioSciences Co., Libertyville, IL., USA) applied 2 WBFH, 5) 200 $mg \cdot L^{-1}$ PDJ applied 4 WBFH, 6) scoring with girdling pliers (Optima Products, Paarl, South Africa) 10 cm above graft union, 4 WBFH, and 7) scoring 2 WBFH.

Treatments were randomised in six blocks with two trees per plot, a guard tree between treatments and guard rows between treatment rows. A nonionic surfactant, Break-Thru, a.i. polyether-polymethylsiloxane-copolymer (Western Farm Service, Inc., Fresno, CA., USA) at 0.5 $ml \cdot L^{-1}$ was added to spray treatments. Spray treatments were applied with a truck mounted motorised sprayer to run-off. The first fruit were harvested on 4 May 2005 and the remaining fruit on 17 May 2005. GA_3 at 50 $mg \cdot L^{-1}$ was unfortunately sprayed over all the treatments 5 days after the first harvest date due to a misunderstanding between the producer and his workers.

Data collection: All fruit were harvested and weighed per replicate on each harvest date to determine the harvest distribution. A sample of 20 fruit per replicate was taken on each harvest date to assess fruit size, colour and maturity. An additional 40 fruit per replicate were sampled on the second harvest date to assess storability and shelf life. These fruit were stored in regular atmosphere at -0.5 °C for 3 months, after which half the fruit were used to assess fruit quality. Astringency of the remaining fruit was removed by Hortec (a commercial research institution; Grabouw, South Africa) by keeping fruit for 24 hours in 80% CO_2 at 20 °C. Shelf life was assessed after a further 5 days at 15 °C.

Flesh firmness, fruit colour and total soluble solids (TSS) were determined after harvest, storage and shelf life. Flesh firmness was determined on pared, opposite cheeks of the fruit using a GÜSS fruit texture analyser (GS, GÜSS Manufacturing (Pty.) Ltd., Strand, South Africa) with an 11 mm tip. Fruit colour was assessed using a sweet persimmon colour chart (Sweet Persimmon Growers Trust, South Africa; values 1-8 where 8 = red/orange and 1 = green) and a Minolta chroma meter (Model CR-400, Minolta Co. Ltd., Tokyo, Japan; second harvest only). Hue angels (H°) range between 0° = red-purple, 90° = yellow, 180° = bluish-green and 270° = blue, and provide an appropriate means to express differences in colour of persimmon peel. Slices cut from each side of the fruit were pooled and juiced and TSS measured using a refractometer (PR32, Atago Co. Ltd., Tokyo, Japan). Astringency was determined after shelf life by soaking halved fruits in ferric chloride (50 $g\ L^{-1}$). The degree of astringency was evaluated on a scale from 1 (no colour, non-astringent) to 8 (totally black, fully astringent) by using a persimmon tannin chart developed by Plant Protection and Inspection Services (PPIS), Bet Dagan, Israel.

Three healthy fruits per sample were used to determine internal ethylene content after the second harvest, storage and shelf life. Sample fruit were dipped in a desiccator under the surface of distilled water with a submerged container. Fruit were then decompressed using a vacuum pump in order to extract the internal gas from the fruit. The gas vacuumed out of the fruit was extracted out of the container with a gas tight syringe through a rubber serum stopper on the upper of the container. Samples (3 cm^3) were injected into a gas chromatograph (Varian, Model 3300, Variant Instrument Group, Palo Alto, CA., USA) equipped with a Poropak Q column and a flame ionization detector. The detector temperature was set at 250 ℃, oven temperature at 60 ℃ and the injector at -1℃. Ethylene was measured by comparing the output area of the sample to the area of a 1.1 $\mu L \cdot L^{-1}$ ethylene standard. The following equation was used to determine ethylene concentration in $\mu L \cdot L^{-1}$ air.

$$\text{Ethylene } \mu L \cdot L^{-1} = \frac{\text{peak area of sample}}{\text{peak area of standard}} \times \ \mu L \cdot L^{-1} \text{of standard}$$

2005/2006

Plant material and experimental design: The trial was repeated in the same orchard as in 2004/2005 with the following treatments: 1) control, 2) 50 $mg \cdot L^{-1}$ GA_3 applied on 19 April 2006 2 WBFH, 3) 125 $mg \cdot L^{-1}$ AVG applied 3 WBFH, 4) MCP (AgroFresh Inc., Philadelphia, USA) applied at industry recommended concentration after harvest, 5) 24 $mg \cdot L^{-1}$ ethephon (Bayer CropScience Co., East Hawthorn, Australia) applied 4 WBFH, and 6) scoring with girdling pliers, 10 cm above the grafting union 3 WBFH. Treatments were randomised in seven blocks with two trees per plot, a guard tree between treatments and guard rows between treatment rows. Break-Thru (0.5 $ml \cdot L^{-1}$) was added to all spray treatments and treatments were applied as described for 2004/2005. The first fruit were harvested on 3 May 2006 and the remaining fruit on 15 May 2006. Fruit for the MCP treatment were taken to Experico (a commercial research institution; Stellenbosch, South Africa) immediately after the second harvest and gassed with MCP in an airtight container at -1 °C for 24 hours. Fruit were stored at -0.5 °C after treatment.

Data collection: All fruit were harvested and weighed at each harvest date to determine the harvest distribution. A sample of 20 fruit per treatment replicate was randomly taken on each harvest date to assess size, colour and maturity. An additional 40 fruit per replicate were sampled on the second harvest date to assess storability and shelf life. These fruit were stored in regular atmosphere at -0.5 °C for 3 months. Ethephon-treated fruit were stored separately, but at the same temperature as other treatments. Half the stored fruit were used to assess fruit quality immediately after storage. Astringency of the remaining fruit was removed as described for 2004/2005 and shelf life was assessed after a further 7 days at 15 °C. Maturity parameters were assessed as previously described with the exception that a PPIS persimmon colour chart (values 1-8 where 1 = red/orange; 8 = green) was used for colour assessment. *Alternaria alternata* infection (confirmed by the Disease Clinic, Department of Plant Pathology, University of Stellenbosch, Stellenbosch, South Africa) was assessed after storage and shelf life by using an alternaria infection chart developed by PPIS.

Statistical analysis: Data were analysed with the General Linear Models (GLM) procedure in the SAS (Statistical Analysis System) computer program (SAS Enterprise Guide 3.0; SAS Institute, 2004, Cary, USA). Intervals between colour chart values were assumed to be equal so to allow analysis as an interval variable.

Results

2004/2005

Harvest distribution: GA_3 significantly reduced the percentage of fruit harvested on the first harvest date compared to PDJ applied 4 WBFH and scoring 2 or 4 WBFH (Fig. 1). Scoring 2 WBFH advanced ripening compared to AVG. None of the treatments changed the harvest distribution compared to the control.

Fruit colour: No significant differences were found in colour chart values on the first harvest date (Table 1). According to colour chart values, GA_3-treated fruit harvested on the second date were significantly greener than fruit of the control, scoring and PDJ (4 WBFH) treatments (Table 1). Also, AVG-treated fruit were greener than fruit of the scoring treatment. Fruit from trees scored 2 WBFH were lower in hue on the second harvest date compared to fruit of other treatments except for scoring 4 WBFH (Table 2).

According to colour chart values, fruit from trees scored 2 WBFH were more orange after storage compared to fruit of other treatments (Table 1). This was also reflected in the lower hues of these fruit compared to fruit of the AVG, GA_3 and PDJ (2 WBFH) treatments (Table 2). According to colour chart values, GA_3-treated fruit remained greener during storage compared to fruit of the control, scoring and PDJ treatments. Hue angles after storage similarly indicate the greener colour of GA_3-treated fruit compared to fruit of the control, scoring and PDJ (2 WBFH) treatments (Table 2). Differences in colour chart values and hue angles after 5 days shelf life were not statistically significant. Fruit of the different treatments underwent comparable changes in colour during cold storage and shelf life (Table 1, 2).

Fruit maturity: No significant differences were found for fruit firmness, TSS and internal ethylene levels at harvest (Table 3, 4, 5). Differences in firmness became evident after storage with GA_3-treated fruit significantly firmer compared to fruit of the control, scoring and PDJ (2 WBFH) treatments (Table 3). Fruit from trees scored 2 WBFH were significantly softer after storage than fruit of other treatments. These fruit decreased more in firmness during storage than fruit of the GA_3, AVG and PDJ (4 WBFH) treatments, but the treatment effect was not significant at the 5% level ($p = 0.0640$). Fruit of all treatments were soft at the end of shelf life. Changes in fruit firmness over shelf life and cumulative change over the storage and shelf life periods were not significant for any of the treatments.

Differences in TSS and internal ethylene levels became evident only after the 5 day shelf life period. Fruit treated with PDJ 2 WBFH showed higher TSS levels compared to control, AVG and GA_3-treated fruit after shelf life (Table 4). AVG fruit had lower TSS levels than fruit from scored trees. Despite these differences in TSS levels after shelf life, changes in TSS during storage, shelf life, and cumulatively over storage and shelf life did not differ significantly between treatments.

Internal ethylene levels increased during storage in fruit of all treatments and decreased during shelf life (Table 5). Due to this, the absolute changes in internal ethylene levels from the second harvest date until after the shelf life period are not presented. Fruit scored 4 WBFH had significantly higher internal ethylene levels after shelf life compared to the fruit of the AVG, GA_3, scoring (2 WBFH) and PDJ (2 WBFH) treatments (Table 5). However, changes in internal ethylene levels during storage and during shelf life did not differ significantly between treatments. Treatments had no significant effect on residual astringency after shelf life (data not presented).

2005/2006

Harvest distribution: GA_3 applied 2 WBFH decreased the percentage of fruit harvested on the first harvest date (< 1%) compared to the scoring (24%) and ethephon (49%) treatments (Fig. 2). Ethephon significantly increased the percentage of fruit harvested on the first harvest date compared to other treatments.

Fruit colour: According to colour chart values, ethephon-treated fruit picked on the first harvest date were significantly more orange compared to other treatments (Table 6). However, differences in hue angles on the first harvest date were not significant (Table 7). On the second harvest date, colour chart values as well as hue angles indicate that ethephon-treated fruit were more orange, except for the scoring treatments, than fruit of other treatments. According to colour chart values and hue angles, GA_3-treated fruit harvested on the second harvest date were significantly greener compared to fruit of other treatments. These fruit were still greener after storage and shelf life compared to fruit of other treatments (Table 6, 7). According to colour chart values, but not hue angles, fruit treated with MCP were also greener after shelf life than fruit of other treatments. According to hue angles, ethephon-treated fruit were more orange after shelf life than fruit of other treatments except for scoring. Fruit of different treatments showed comparable changes in hue during storage and shelf life (Table 7). In contrast, colour chart values indicate that GA_3-treated fruit changed less in colour from harvest until after shelf life except for the MCP treatment. MCP-treated fruit changed less in colour chart value during shelf life and cumulatively over the entire storage and shelf life period than fruit of the control, AVG and ethephon treatments (Table 6).

Fruit maturity: Treatments did not affect fruit size (data not presented). Ethephon reduced fruit firmness at both harvest dates (Table 8). GA_3-treated fruit were firmer on the second harvest date and after storage compared to fruit of the control, ethephon and scoring treatments (Table 8). GA_3 and MCP-treated fruit were firmer after shelf life than fruit of other treatments. Fruit of the control, AVG, scoring and ethephon treatments did not differ in firmness after storage and shelf life. GA_3-treated fruit changed less in firmness during storage than fruit of other treatments, except for the ethephon treatment. MCP-treated fruit also changed less in firmness during storage than fruit of the control, AVG and scoring treatments. MCP fruit retained their firmness over shelf life compared to other treatments, but differences were not significant ($p = 0.1401$). Fruit of the GA_3, MCP and ethephon treatments decreased less in firmness from harvest until after shelf life than fruit of the control, AVG and scoring treatments.

Treatments had no effect on TSS levels at harvest or after storage (Table 9). GA_3 and MCP-treated fruit had the highest TSS levels after shelf life, differing significantly from other treatments. TSS levels of MCP fruit decreased less during shelf life compared to other treatments except for GA_3. GA_3-treated fruit decreased less in TSS than fruit of the control and ethephon treatments.

Internal ethylene levels of fruit of all treatments increased from very low levels at harvest to high levels at the end of the storage period (Table 10). Ethylene levels decreased again during shelf life, but remained significantly higher in ethephon-treated fruit at the end of the shelf life period compared to fruit of all other treatments except for scoring. Absolute changes in internal ethylene levels from after the second harvest date until after the shelf life period are not presented for the same reason as in 2004/2005.

Due to subjective nature of *A. alternata* assessment, lower infection levels were recorded after shelf life than after storage (Table 11). Fruit treated with ethephon showed more severe *A. alternata* infection after storage compared to fruit of other treatments. GA_3 significantly reduced the percentage of fruit infected with *A. alternata* compared to other treatments except for MCP. MCP-treated fruit were significantly less infected than fruit from the control and ethephon treatments. A greater percentage of fruit from the ethephon treatment were infected with *A. alternata* compared to control, GA_3, AVG and MCP-treated fruit after shelf life (Table 11). GA_3 reduced the incidence of *A. alternata* infection compared to the control, scoring and ethephon treatments. However, AVG, MCP and scoring treatments were similarly infected with *A. alternata* after shelf life. MCP and GA_3-treated fruit had higher astringency values after shelf life compared to fruit of the AVG, scoring and ethephon treatments (Table 11).

Discussion

The decision on when to begin harvesting 'Triumph' persimmons is usually based on fruit colour (colour chart values between 3 and 5 on the PPIS colour chart). Harvest has to terminate before fruit firmness drops to low, especially if fruit is intended for long term storage (Ben-Arie et al., 1986). According to The Perishable Products Export Control Board (PPECB) standards, fruit firmness values, for persimmons, have to range between 5 and 10 kg for packing and marketing (Aronson, personal communication). These limitations of colour and firmness pose a serious problem with regards to condensing harvesting, packing and marketing. Under South African conditions where 'Triumph' is the only astringent cultivar planted, treatments that advance or delay fruit ripening in the orchard and/or increase storability of fruit may extend the harvesting and marketing periods of 'Triumph' persimmon. We evaluated the use of GA_3 and AVG to delay and PDJ, ethephon and scoring to advance ripening. The effects of these treatments as well as a post harvest application of MCP on storability and shelf life of fruit were determined.

GA_3 applied two weeks before harvest delayed colour development (Table 1, 2, 6, 7) and fruit softening (2005/2006; Table 8), thereby delaying harvest (Fig.1, 2). This is in agreement with results of Ben-Arie et al. (1986) who reported that GA_3 strongly delays ripening of persimmon fruit and thereby extend the harvesting period. Due to practical considerations, we had to harvest all fruit on the second harvest date. However, the greener colour of GA_3-treated fruit (Table 1, 6) indicates that harvesting of these fruit could have been delayed even further.

According to colour chart values, GA_3 also retarded colour development during storage in the 2005/2006 season. Together with the delay in colour development before the second harvest, this resulted in fruit that was still greener at the end of shelf life (Table 6). In contrast, fruit of all treatments showed comparable changes in hue angles during storage and shelf life (Table 7), suggesting that differences in colour after storage and shelf life were related to differences present at harvest. The disparity between changes in colour chart values and hue angles during storage and shelf life possibly relates to the subjective nature of the colour chart assessment of the whole fruit compared to the objective measurement with the colorimeter on a small (8 mm diameter), localised area of the peel. Optimum colour chart values for marketing are below 4 on the PPIS colour chart (Swart, personal communication). According to colour chart values, GA_3-treated fruit were almost of marketable colour (4.6 on colour chart) (Table 6). It must be taken into account that these fruit could have been harvested later, but all fruit were harvested at the second date. The comparable changes in colour development during storage and shelf life in the 2004/2005 for fruit of different treatments season may relate to the second GA_3 application that was accidentally applied over all treatments 8 days before the second harvest date (Table 1, 2)

In the 2005/2006 season, GA_3 and MCP reduced fruit softening during storage. This, together with higher firmness at harvest in the case of GA_3, resulted in higher fruit firmness after storage and shelf life (Table 8). MCP and GA_3-treated fruit which also maintained higher TSS levels over shelf life (Table 9), were significantly lower in internal ethylene compared to the ethephon treatment (Table 10), and were less infected by *A. alternata* compared to the control (Table 11). Thus MCP and GA_3 enhanced the keeping quality of persimmon fruit after a period of 3 months storage as well as 7 days shelf life. The effect of GA_3 is in agreement with previous research showing that GA_3 application enhances the keeping quality of persimmon fruit after harvest (Kitagawa et al., 1966) and reduces *A. alternata* infection (Esthel et al., 2000). MCP has also previously been found to increase the shelf life of ‘Fuyu’ persimmon fruit (20 ± 2 ˚C) after a 3 months cold storage period (0 ˚C) (Kim and Lee, 2005; Tsviling et al., 2003). In general, the deastringefication treatment was not very effective. GA_3 and MCP-treated fruit remained more astringent after deastringefication (Table 11), implying that the fruit were less ripe compared to fruit of other treatments. Esthel et al. (2000) suggest that fruit softening may be a factor in fungal development of infected fruit. Hence, the beneficial effect of GA_3 and MCP on *A. alternata* infection is probably due to their effect on ripening. Alternatively Ben-Arie et al. (1997) suggested that GA_3 application increases levels of cell wall carbohydrates thereby increasing resistance to *A. alternata* infection. As we did not apply a preventative treatment prior to storage, *A. alternata* infection and differences between treatments may be more conspicuous than would have been the case if normal disinfective industry treatments were applied. The beneficial effects of GA_3 on storability and keeping quality of fruit were less apparent in the 2004/2005 season, probably due to the 50 $mg \cdot L^{-1}$ GA_3 that was accidentally sprayed over all the treatments 8 days before the second harvest.

Turning now to treatments applied to advance maturity. AVG and PDJ had little effect on fruit ripening and proved ineffective in extending the harvesting window (Fig 1, 2) as well as in improving post-harvest quality and storability in ‘Triumph’ persimmon (Table 3 to 5, 8 to 11). Previously, PDJ was found to advance ripening in ‘Fuyu’ persimmon (Fujisawa et al. 1997). The accidental GA_3 cover spray may be the reason for the poor response of PDJ. Hence further evaluation is advised before deciding on the efficacy of PDJ. The inefficiency of AVG is also contrary to previous findings with non-astringent persimmon (Ben-Arie et al. 1997). Internal ethylene levels, which AVG is supposed to reduce, were very low at harvest and only reached high levels during storage in all treatments (Table 5, 10). Interestingly AVG did not inhibit the development of high internal ethylene levels during storage as found, for example, in apple (Bufler, 1984). It is uncertain why AVG was ineffective. A possible explanation may be that ethylene could have been synthesised from ACC that was already present prior to AVG application. Since AVG only inhibits ACC synthase, the availability of sufficient ACC may still induce autocatalytic ethylene synthesis (Yang and Hoffman, 1984). We applied AVG 3 WBFH, while in apples AVG is applied 4 weeks before harvest (Bufler, 1984). However, in peach AVG is only applied 10 days before harvest (Vizzotto et al., 2002).

Ethephon was the only treatment that significantly advanced harvest maturity compared to the control (Fig. 2). Ethephon treatment increased orange colour and reduced fruit firmness at harvest (Table 6, 7, 8). This is in agreement with previous research. Itamura et al. (2003) found that ethephon sprayed on 'Hiratanenashi' persimmon prior to harvest promoted colour development while Kim et al. (2004) reported that ethephon significantly reduced the firmness of sweet persimmon. The lower hue of fruit at the second harvest related into a lower hue compared to other treatments, except for the scoring treatment after shelf life. Ethephon-treated fruit did not differ significantly from control fruit in firmness, TSS as well as residual astringency after shelf life (Table 8, 9, 11). Although this suggests that the keeping quality of ethephon-treated fruit were not worse than that of control fruit, only fruit treated with GA_3 and MCP were still of acceptable quality after shelf life. The lower decrease of ethephon-treated fruit in firmness over the storage and shelf life period compared to the control may relate to the lower firmness of these fruit at the onset of storage (Table 8). In addition, ethephon-treated fruit were significantly more infected with *A. alternata* (Table 11) and had significantly higher internal ethylene levels after shelf life (Table 10), indicative of advanced maturity.

Scoring 2 WBFH slightly advanced fruit maturity in the 2004/2005 season as evident from the lower hue angles on the second harvest date (Table 2), more orange colour chart value after storage (Table 1), and lower firmness after storage (Table 3). This is in agreement with Dennis (1968) who found that scoring prior to harvest advances maturity in apples and pears. However, scoring 4 WBFH in the 2004/2005 season and scoring 3 WBFH in 2005/2006 had no effect on colour development, fruit maturity and keeping quality. Although scoring closer to harvest may have some effect on ripening, the effect does not appear to be sufficient to have a major influence on the harvest distribution (Fig. 1) and to thereby justify the treatment.

The gibberellin biosynthesis inhibitor, paclobutrazol, could be included in future experiments aimed at advancing persimmon maturity. Previously, spring soil application of paclobutrazol has been shown to advance the ripening of persimmons by two to three weeks (Ben-Arie et al., 1997). However, the persistence of paclobutrazol in the plant and soil, and enhanced fruit deterioration during storage should be kept in mind (Ben-Arie et al., 1997).

Conclusion

The results reported here indicate that the harvesting and marketing period of 'Triumph' persimmon can be extended by applying GA_3 two weeks prior to harvest and ethephon four weeks prior to harvest. The increased storability of MCP-treated fruit may allow harvesting at more advanced maturity, thereby extending the harvesting window. It would be necessary to market fruit as soon as possible after harvest or improve the keeping quality of fruit sprayed with ethephon. Whether the latter can be achieved by combining ethephon with GA_3 and/or MCP treatments requires further study.

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Table 1. Effect of pre-harvest treatments on colour chart values (1-8 where 8 = red/orange; 1 = green) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 5 days shelf life at 15 ºC during the 2004/2005 season. Means are separated by LSD (5%) where the F-value was significant at Pr > F 0.0500.

Treatments	Time of application (WBFH[y])	First harvest 4 May 2005	Second harvest 17 May 2005	After storage	After shelf life	Change during storage period	Change during shelf life period	Change during storage and shelf life period
Control		4.8[ns]	4.6 abc[z]	5.0 b	5.2[ns]	-0.4[ns]	-0.2[ns]	-0.6[ns]
GA_3 (50mg·L^{-1})	2	4.7	4.3 d	4.5 c	4.7	-0.1	-0.3	-0.4
AVG (125 mg·L^{-1})	3	4.9	4.5 cd	4.7 bc	4.8	-0.3	-0.1	-0.3
PDJ (200 mg·L^{-1})	4	4.7	4.7 abc	4.9 b	4.9	-0.1	0.0	-0.2
PDJ (200 mg·L^{-1})	2	5.0	4.6 bcd	4.9 b	5.0	-0.4	-0.1	-0.4
Scoring	4	4.9	4.8 ab	4.9 b	5.1	-0.1	-0.2	-0.3
Scoring	2	5.0	4.9 a	5.3 a	5.3	-0.5	-0.1	-0.4
Pr > F		0.5224	0.0059	0.0010	0.1517	0.1814	0.6565	0.3204

[ns] not significant

[z] treatments with different letters differ significantly at p > 0.05

[y] weeks before first harvest

Table 2. Effect of pre-harvest treatments on hue (º) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 5 days shelf life at 15 ºC during the 2004/2005 season. Hue angles range between 0º = red/purple and 90º = yellow. Means are separated by LSD (5%) where the F-value was significant at Pr > F 0.0500.

Treatments	Time of application (WBFH[y])	Second harvest 17 May 2005	After storage	After shelf life	Change during storage period	Change during shelf life period	Change during storage and shelf life period
Control		72.1 b[z]	64.5 bc	62.0 [ns]	7.5[ns]	2.5[ns]	10.1[ns]
GA_3 (50mg·L^{-1})	2	74.1 a	68.2 a	65.8	4.8	2.5	8.3
AVG (125 mg·L^{-1})	3	72.9 ab	66.3 ab	64.6	6.6	1.7	8.3
PDJ (200 mg·L^{-1})	4	72.3 ab	65.9 ab	64.6	6.4	1.3	7.7
PDJ (200 mg·L^{-1})	2	72.1 b	64.3 bc	64.1	7.7	0.2	7.9
Scoring	4	71.2 bc	64.3 bc	63.0	6.8	1.3	8.2
Scoring	2	69.6 c	62.5 c	61.7	7.1	0.8	7.9
Pr > F		0.0035	0.0028	0.0966	0.6861	0.6914	0.4905

[ns] not significant

[z] treatments with different letters differ significantly at p >0.05

[y] weeks before first harvest

Table 3. Effect of pre-harvest treatments on fruit firmness (kg) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 5 days shelf life at 15 ºC during the 2004/2005 season. Means are separated by LSD (5%) where the F-value was significant at Pr > F 0.0500.

Treatments	Time of application (WBFH[y])	First harvest 4 May 2005	Second harvest 17 May 2005	After storage	After shelf life	Change during storage period	Change during shelf life period	Change during storage and shelf life period
Control		9.4[ns]	10.4[ns]	5.4 b[z]	1.6[ns]	5.1 [ns]	3.8 [ns]	8.8 [ns]
GA_3 ($50 mg\cdot L^{-1}$)	2	9.2	11.2	8.0 a	3.1	3.2	5.0	8.1
AVG ($125\ mg\cdot L^{-1}$)	3	9.6	10.5	6.8 ab	3.9	3.7	2.9	6.6
PDJ ($200\ mg\cdot L^{-1}$)	4	10.0	10.0	6.5 ab	3.5	3.5	3.0	6.5
PDJ ($200\ mg\cdot L^{-1}$)	2	9.2	9.9	5.6 b	2.5	4.2	3.1	7.4
Scoring	4	10.2	10.5	5.2 b	2.0	5.3	3.2	8.5
Scoring	2	10.3	9.5	3.1 c	1.2	6.4	1.9	8.3
Pr > F		0.3983	0.1492	0.0017	0.2711	0.0640	0.3055	0.4621

[ns] not significant

[z] treatments with different letters differ significantly at p > 0.05

[y] weeks before first harvest

Table 4. Effect of pre-harvest treatments on TSS (º brix) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 5 days shelf life at 15 ºC during the 2004/2005 season. Means are separated by LSD (5%) where the F-value was significant at Pr > F 0.0500.

Treatments	Time of application (WBFH[y])	First harvest 4 May 2005	Second harvest 17 May 2005	After storage	After shelf life	Change during storage period	Change during shelf life period	Change during storage and shelf life period
Control		20.8[ns]	20.7[ns]	19.7[ns]	18.2 cd[z]	1.0[ns]	1.5[ns]	2.5[ns]
GA_3 (50mg·L^{-1})	2	21.6	20.8	19.8	18.2 bcd	1.1	1.6	2.7
AVG (125 mg·L^{-1})	3	21.0	20.7	19.5	17.7 d	1.2	1.8	3.0
PDJ (200 mg·L^{-1})	4	21.4	20.7	19.6	18.4 abcd	1.1	1.2	2.3
PDJ (200 mg·L^{-1})	2	21.6	21.2	19.9	19.1 a	1.3	0.8	2.1
Scoring	4	21.4	21.2	19.6	18.9 abc	1.6	0.8	2.3
Scoring	2	21.6	21.2	19.6	19.0 ab	1.6	0.6	2.2
Pr > F		0.1648	0.2353	0.8355	0.0110	0.1121	0.1329	0.5827

[ns] not significant

[z] treatments with different letters differ significantly at p > 0.05

[y] weeks before first harvest

Table 5. Effect of pre-harvest treatments on internal ethylene concentration ($\mu L \cdot L^{-1}$) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 5 days shelf life at 15 ºC during the 2004/2005 season. Means are separated by LSD (5%) where the F-value was significant at Pr > F 0.0500.

Treatments	Time of application (WBFH[y])	Second harvest 17 May 2005	After storage	After shelf life	Change during storage period	Change during shelf life period
Control		0.18[ns]	0.94[ns]	0.59 ab[z]	-0.76[ns]	0.35[ns]
GA_3 ($50 mg \cdot L^{-1}$)	2	0.21	0.42	0.14 b	-0.21	0.28
AVG ($125\ mg \cdot L^{-1}$)	3	0.21	0.93	0.16 b	-0.72	0.77
PDJ ($200\ mg \cdot L^{-1}$)	4	0.19	0.56	0.18 b	-0.37	0.39
PDJ ($200\ mg \cdot L^{-1}$)	2	0.12	0.83	0.52 ab	-0.70	0.30
Scoring	4	0.27	1.24	1.00 a	-0.97	0.24
Scoring	2	0.21	0.75	0.31 b	-0.54	0.44
Pr > F		0.8744	0.4889	0.0454	0.4123	0.9407

[ns] not significant

[z] treatments with different letters differ significantly at p > 0.05

[y] weeks before first harvest

72

Table 6. Effect of pre- and post-harvest treatments on colour chart values (1-8 where 1 = red/orange; 8 = green) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 7 days shelf life at 15 ºC during the 2005/2006 season. Means are separated by LSD (5%) at Pr > F 0.0500.

Treatments	Time of Application	First harvest 3 May 2006	Second harvest 15 May 2006	After storage	After shelf life	Change during storage period	Change during shelf life period	Change during storage and shelf life period
Control		5.0 a[z]	4.4 b	3.9 b	2.8 c	0.41 a	1.2 a	1.6 a
GA_3 (50mg·L^{-1})	2 WBFH[y]	5.0 a	5.3 a	5.4 a	4.6 a	-0.17 b	0.9 ab	0.7 c
AVG (125 mg·L^{-1})	3 WBFH	5.2 a	4.6 b	4.2 b	2.8 c	0.40 a	1.4 a	1.8 a
MCP	After 2nd harvest	4.9 a	4.5 b	4.1 b	3.7 b	0.37 a	0.4 b	0.8 bc
Ethephon (24 mg·L^{-1})	4 WBFH	4.4 b	3.9 c	3.7 b	2.2 c	0.16 ab	1.5 a	1.7 a
Scoring	3 WBFH	5.0 a	4.2 bc	3.8 b	2.8 c	0.41 a	1.0 ab	1.4 ab
Pr > F		0.0027	<0.0001	<0.0001	<0.0001	0.0848	0.0393	0.0089

[ns] not significant

[z] treatments with different letters differ significantly at p > 0.05

[y] weeks before first harvest

Table 7. Effect of pre- and post-harvest treatments on hue (º) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 7 days shelf life at 15 ºC during the 2005/2006 season. Hue angles range between 0º = red/purple and 90º = yellow. Means are separated by LSD (5%) where the F-value was significant at Pr > F 0.0500.

Treatments	Time of application	First harvest 3 May 2006	Second harvest 15 May 2006	After storage	After shelf life	Change during storage period	Change during shelf life period	Change during storage and shelf life period
Control		75.6^{ns}	74.7 b^{z}	71.9 b	65.4 b	2.8^{ns}	6.5^{ns}	9.3^{ns}
GA_3 (50mg·L^{-1})	2 WBFH^{y}	77.0	81.7 a	80.2 a	71.6 a	1.4	8.6	10.0
AVG (125 mg·L^{-1})	3 WBFH	76.0	75.2 b	72.4 b	65.3 b	2.8	7.2	10.0
MCP	After 2nd harvest	74.8	74.5 b	71.3 b	65.4 b	3.2	5.9	9.1
Ethephon (24 mg·L^{-1})	4 WBFH	73.8	71.5 c	70.3 b	61.7 c	1.2	8.6	9.7
Scoring	3 WBFH	75.2	73.9 bc	70.4 b	64.0 bc	3.6	6.4	10.0
Pr > F		0.4170	<0.0001	<0.0001	<0.0001	0.5146	0.4037	0.9723

^{ns} not significant

^{z} treatments with different letters differ significantly at p > 0.05

^{y} weeks before first harvest

Table 8. Effect of pre- and post-harvest treatments on fruit firmness (kg) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 7 days shelf life at 15 ºC during the 2005/2006 season. Means are separated by LSD (5%) where the F-value was significant at Pr > F 0.0500.

Treatments	Time of application	First harvest 3 May 2006	Second harvest 15 May 2006	After storage	After shelf life	Change during storage period	Change during shelf life period	Change during storage and shelf life period
Control		10.2 a[z]	10.9 b	3.3 c	1.3 b	7.6 a	2.0[ns]	9.7 a
GA_3 ($50 mg \cdot L^{-1}$)	2 WBFH[y]	10.4 a	12.3 a	8.8 a	5.4 a	3.5 c	3.4	6.9 b
AVG ($125 mg \cdot L^{-1}$)	3 WBFH	10.8 a	11.3 ab	3.6 c	1.4 b	7.7 a	2.2	9.9 a
MCP	After 2nd harvest	10.5 a	11.7 ab	6.0 b	5.2 a	5.7 b	0.8	6.5 b
Ethephon ($24 mg \cdot L^{-1}$)	4 WBFH	7.4 b	8.6 c	3.9 c	1.4 b	4.7 bc	2.6	7.3 b
Scoring	3 WBFH	10.5 a	10.8 b	3.5 c	1.3 b	7.3 a	2.3	9.5 a
Pr > F		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.1401	<0.0001

[ns] not significant

[z] treatments with different letters differ significantly at p > 0.05

[y] weeks before first harvest

Table 9. Effect of pre- and post-harvest treatments on TSS (º brix) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 7 days shelf life at 15 ºC during the 2005/2006 season. Means are separated by LSD (5%) where the F-value was significant at Pr > F 0.0500.

Treatments	Time of application	First harvest 3 May 2006	Second harvest 15 May 2006	After storage	After shelf life	Change during storage period	Change during shelf life period	Change during storage and shelf life period
Control		20.4^{ns}	20.6^{ns}	20.7^{ns}	17.7 b^{z}	0.0^{ns}	2.9 a	2.9 a
GA_3 (50mg·L^{-1})	2 WBFH^{y}	20.6	21.1	21.3	20.1 a	-0.2	1.2 bc	1.0 bc
AVG (125 mg·L^{-1})	3 WBFH	20.2	20.7	20.2	18.0 b	0.5	2.2 ab	2.7 a
MCP	After 2nd harvest	20.4	20.5	20.8	20.3 a	-0.3	0.5 c	0.2 c
Ethephon (24 mg·L^{-1})	4 WBFH	19.6	20.3	20.7	18.3 b	-0.4	2.4 a	2.0 ab
Scoring	3 WBFH	20.3	20.6	20.1	18.1 b	0.5	2.0 ab	2.5 a
Pr > F		0.3113	0.6642	0.1595	<0.0001	0.3175	0.0007	<0.0001

^{ns} not significant

^{z} treatments with different letters differ significantly at p >0.05

^{y} weeks before first harvest

Table 10. Effect of pre- and post-harvest treatments on internal ethylene concentration ($\mu \cdot L^{-1}$) of 'Triumph' persimmons at harvest, after a 3 month storage period at -0.5 ºC and after 7 days shelf life at 15 ºC during the 2005/2006 season. Means are separated by LSD (5%) where the F-value was significant at Pr > F 0.0500.

Treatments	Time of application	Second harvest 15 May 2006	After storage	After shelf life	Change during storage period	Change during shelf life period
Control		0.029^{ns}	0.676^{ns}	0.199 b^{z}	-0.649^{ns}	0.478^{ns}
GA_3 (50mg$\cdot L^{-1}$)	2 WBFH^{y}	0.043	0.339	0.082 b	-0.296	0.257
AVG (125 mg$\cdot L^{-1}$)	3 WBFH	0.028	0.574	0.238 b	-0.546	0.336
MCP	After 2nd harvest	0.021	0.435	0.122 b	-0.414	0.312
Ethephon (24 mg$\cdot L^{-1}$)	4 WBFH	0.051	0.601	0.559 a	-0.550	0.041
Scoring	3 WBFH	0.041	0.558	0.343 ab	-0.517	0.169
Pr > F		0.4673	0.2970	0.0108	0.3083	0.2603

^{ns} not significant

^{z} treatments with different letters differ significantly at p > 0.05

^{y} weeks before first harvest

Table 11. Effect of pre- and post-harvest treatments on *Alternaria alternata* infection (% of 20 fruit) after a 3 month storage period at -0.5 ºC and 7 days shelf life at 15 ºC of 'Triumph' persimmons during the 2005.2006 season. The effect of treatments on astringency (values 1-8 where 1 = non astringent; 8 = fully astringent) after 7 days shelf life at 15 ºC is also presented. Means are separated by LSD (5%) at Pr > F 0.0500.

		Alternaria infection		Astringency
Treatments	Time of application	After storage	After shelf life	After shelf life
Control		43.7 b[z]	28.3 b	5.7 ab
GA_3 ($50 mg\cdot L^{-1}$)	2 WBFH[y]	10.7 d	10.4 c	6.3 a
AVG ($125 mg\cdot L^{-1}$)	3 WBFH	36.6 bc	24.4 bc	5.5 b
MCP	After 2nd harvest	21.6 cd	20.7 bc	6.3 a
Ethephon ($24 mg\cdot L^{-1}$)	4 WBFH	60.4 a	50.7 a	5.7 b
Scoring	3 WBFH	36.4 bc	33.9 ab	5.6 b
Pr > F		<0.0001	0.0012	0.0351

[z] treatments with different letters differ significantly at p > 0.05

[y] weeks before first harvest

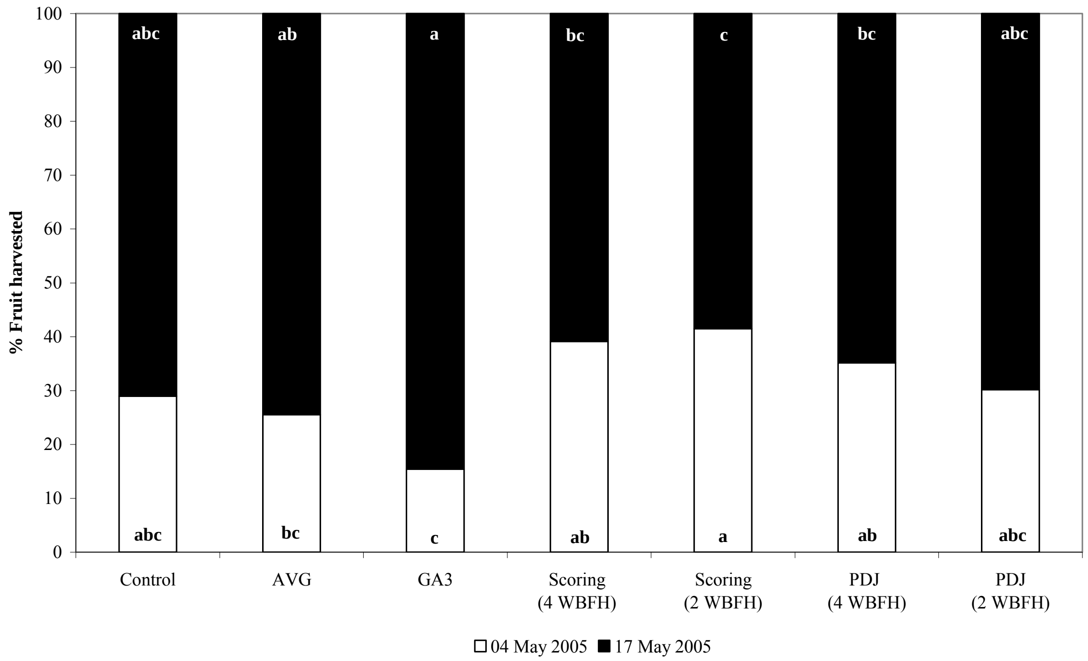

Fig. 1. Effect of pre-harvest treatments applied during the 2004/2005 season on the harvest distribution of 'Triumph' persimmons. Treatments differ at $p < 0.0001$.

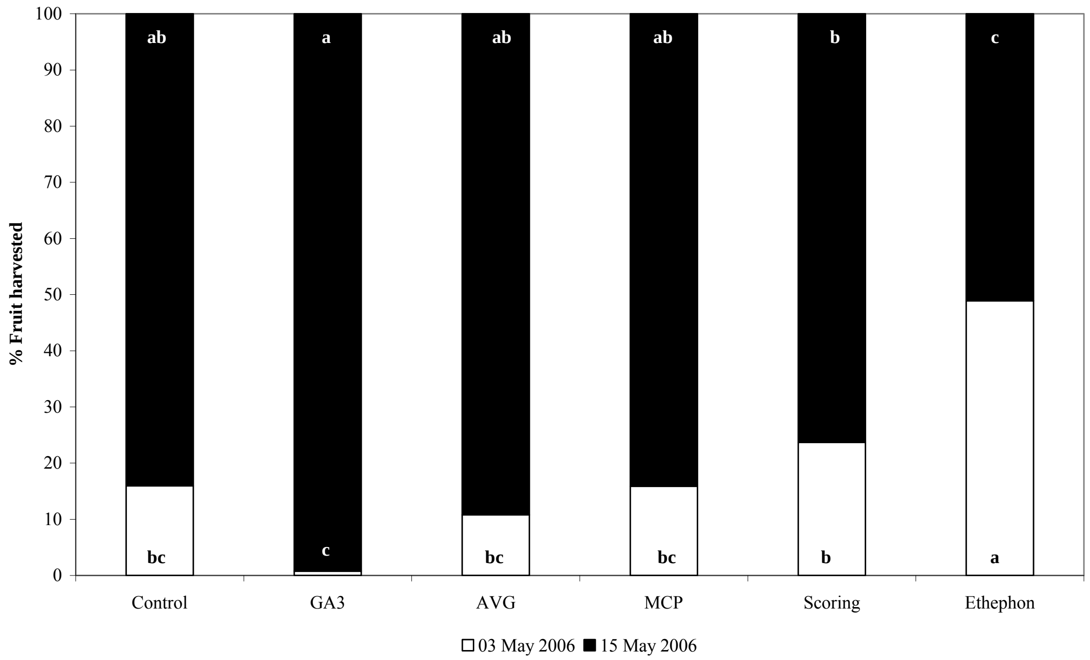

Fig. 2. Effect of pre-harvest treatments applied during the 2005/2006 season on the harvest distribution of 'Triumph' persimmons. MCP was only applied after harvest. Hence, no difference in harvest distribution is expected between this treatment and the control. Treatments differ at $p = 0.0296$.

GENERAL DISCUSSION AND OVERALL CONCLUSIONS

Knowledge on the reproductive and vegetative phenology of 'Triumph' persimmon under South African conditions is needed in order to address problems such as poor fruit set and alternate bearing. Tree training and pruning strategies are also dependant on this knowledge. Actions aimed at ensuring regular high yields of high quality fruit should ensure the presence of good quality bearing wood on the tree. According to our data this would be one-year-old shoots that are longer than 30 cm in length. These shoots may be produced by applying appropriate shoot thinning actions in the winter thus preventing over cropping and ensuring sufficient vegetative growth. When it comes to shoot thinning, it should be taken into account that 'Triumph' initiates flowers distally on one-year-old shoots.

Scoring, but not the industry standard GA_3 application, consistently increased fruit set and yield in young orchards (< 5-year-old). Girdling has been shown to be an effective technique to improve fruit set in persimmon (Hasegawa et al., 2003). However, it has to be kept in mind that heavy cropping may be undesirable in young orchards that still need to fill their allotted space. Sufficient vegetative growth and some level of cropping may be obtained in young orchards by a combination of winter pruning and scoring during anthesis. Reasons for the ineffectiveness of GA_3 applications to improve fruit set and yield in young 'Triumph' persimmon trees are uncertain. In general, GA_3 sprays decreased fruit size although it did not increase the number of fruit per tree. The negative effect of GA_3 on fruit size may reside in the potential positive effect of GA_3 on shoot growth. When it comes to GA_3 applications to improve fruit set in mature orchards, producers must bear in mind that 30% full bloom occurs only two to four days after the first flowers are in full bloom.

The average yield of a full bearing 'Triumph' orchard (> 5-year-old) in Israel is 30 tons per hectare (Llácer and Badenes, 2002). Scoring or girdling, with or without GA_3 applications, increased yield by an average of 16 tons (45%) compared up to the industry standard treatment of 20 µL·L GA_3 at 30 and 70% FB (35 t ha^{-1}). The increase in yield with girdling or scoring was not associated with a decrease in average fruit mass. This could be due to changes in carbohydrate partitioning in favour of fruit growth. However, when in combination with GA_3 application, the higher fruit numbers per tree in response to girdling or scoring did reduce fruit size. The increased fruit load of girdled trees may reduce possible bearing wood for the next season, resulting in the onset of alternate bearing. This can possibly be addressed by shoot pruning during winter or spring, or by fruit thinning in the on-year (Monselise and Goldschmidt, 1982). Pruning and thinning strategies to regulate yield and to ensure the formation of sufficient bearing wood should form part of further research. Flower initiation starts shortly after shoot elongation has ended and soon after fruit set. This should be kept in mind when timing thinning treatments.

Finally, we addressed the highly condensed harvesting period of 'Triumph'. We found that the harvesting period can be extended by a pre-harvest application of GA_3 2 weeks before the first harvest (WBFH) and ethephon (4 WBFH). GA_3 (2 WBFH) delays harvesting whereas ethephon increases fruit colouration and accelerates ripening. Pre-harvest GA_3 application as well as post-harvest MCP treatment can enhance the keeping quality of 'Triumph' fruit during 3 months storage at -0.5 ˚C and 7 days shelf life at 15 ˚C. This could extend the marketing period of fruit. Fruit treated with ethephon showed poor storability. Combinations with GA_3 or MCP may improve the storability of ethephon-treated fruit and should be evaluated in future research.

After this study, we have a better understanding of the reproductive phenology of 'Triumph' persimmon and of how planting systems and pruning strategies could be adapted to increase yield. We have also established that the industry standard GA_3-application to improve fruit set is ineffective in young (< 5 years) orchards. In contrast, scoring or girdling proved highly effective in increasing fruit set in orchards of any age. Fruit set data generated over the duration of this study, with some further verification and fine-tuning, should provide producers with a set of tools to manage crop loads without negatively affecting fruit quality. Lastly, this work shows that the harvest maturity and storability of 'Triumph' persimmon can be manipulated with GA_3, MCP and ethephon treatment.

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