EFFECT OF KAOLIN APPLICATIONS ON POME FRUIT

by

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DECLARATION

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

Signature   Date

SUMMARY

Sunburn is a major problem in the apple industry worldwide. A kaolin product, M-97-009 (100% kaolin), originally developed for insect control, was evaluated for its efficacy in controlling sunburn on pome fruit. Trials were conducted over two seasons in two different areas of the Western Cape, South Africa. During the first season, 'Royal Gala', 'Fuji' and 'Granny Smith' apples were evaluated in the Koue Bokkeveld. The kaolin was mixed with water and applied to the trees by means of a hand-gun regularly throughout the season. In addition to the effect on sunburn, effects on yield, colour development, snout beetle damage and other defects were determined. Sunburn was reduced on all the cultivars tested, although not significantly on 'Granny Smith'. Inconsistent effects on yield parameters were observed. The applications significantly reduced red colour on 'Fuji', but this problem was rectified by an improved application technique the following season.

During the second season, additional apple cultivars and 'Rosemarie' pears were included in the trials. The apple trials were conducted in the Elgin area, and the 'Rosemarie' trial in the Koue Bokkeveld. Surround™ (95% kaolin) was applied to the trees by means of a commercial "blower". The effects on sunburn, yield, colour development and fruit maturity were determined. In contrast to the previous season, sunburn was not reduced on any of the cultivars examined. Yield parameters were not affected except in the case of 'Royal Gala' where the number of fruit was increased, and 'Cripps' Pink' where the number of fruit was reduced. Fruit colour was not affected in the apple cultivars, but chroma of 'Rosemarie' pears was reduced, indicating a less intense colour. The kaolin applications had a variable effect on fruit maturity. The effect of the foliar applications on photosynthetic photon flux density (PPFD), photosynthetic rate, stomatal conductance and transpiration rate was determined. In addition to these spot measurements, photosynthetic light response curves were determined. Measurements were taken on both the inner and outer canopies The applications significantly reduced photosynthetic rates in the inner canopy and reduced the apparent quantum efficiency of leaves on the outer canopy. No significant effect on PPFD was found. It appears that the white coating reflects light and allows less light to penetrate the leaf, thus reducing photosynthesis.

Surround™ treatments could not counteract the damaging effects of the high temperatures experienced in the Western Cape during this season and was not effective as a control measure for sunburn. This does not appear to be a commercially viable solution for the sunburn problem and it would be worthwhile to investigate the use of alternative options, such as evaporative cooling.

OPSOMMING

Effek van kaolien toedienings op kernvruggehalte

Sonbrand is een van die grootste probleme wat wêreldwyd in die appelbedryf ondervind word. 'n Nuwe produk, M-97-009 (100% kaolien), is oorspronklik ontwikkel vir insekbeheer in geïntegreerde plaagbeheer, maar daar is beweer dat dit moontlik sonbrand op kernvrugte kan verminder. Proewe is oor twee seisoene uitgevoer in die Koue Bokkeveld en ook in die Grabouw-omgewing in die Wes-Kaap. Tydens die eerste seisoen is die effek van M-97-009 op 'Royal Gala', 'Fuji' en 'Granny Smith' appels beoordeel. Die kaolien is met water gemeng en deur die loop van die seisoen met 'n handspuit op die bome gespuit. Die effek van die produk op sonbrand, oesgrootte, vruggrootte, kleurontwikkeling, kalanderskade en ander defekte is bepaal. Sonbrand is op alle kultivars verminder, alhoewel nie betekenisvol op 'Granny Smith' nie. Die effek van kaolien op oesparameters was nie konsekwent nie. Die toedienings het kleurontwikkeling op 'Fuji' benadeel, heel moontlik as gevolg van die toedieningstegniek. Met verbeterde toedieningsmetodes die volgende seisoen, is kleur-ontwikkeling van 'Fuji' nie benadeel nie.

Tydens die tweede seisoen is die effek van kaolien op nog appelkultivars en 'Rosemarie' pere ge-evalueer. Die appelproewe is in Elgin uitgevoer, terwyl die 'Rosemarie'–proef in die Koue Bokkeveld uitgelê is. Surround™ (95% kaolien) is met kommersiële spuitpompe toegedien. Weereens is die effek van die produk op sonbrand, oesgrootte, vruggrootte, kleurontwikkeling en vrugrypheid bepaal. Sonbrand is nie verminder nie. Vruglading tydens oes is nie betekenisvol beïnvloed nie, behalwe in die geval van 'Royal Gala' waar die vruglading verhoog is, en 'Cripps' Pink' waar daar minder vrugte op die gespuite bome was. Die Surround™ toedienings het geen uitwerking op kleur van appels gehad nie, maar het die chromawaarde van 'Rosemarie' pere verlaag, d.w.s die vrug-kleur was minder intens. Die kaolienspuite het 'n uiteenlopende effek op vrugrypheid gehad. Fotosintetiese foton vloeddigtheid (FFV), fotosintesetempo, huidmondjieweerstand en transpirasietempo is gemeet en ligreponskurwes van beide die buitenste en binneste blaardak is bepaal. Die Surround™ toedienings het fotosintese van

blare in die binneste gedeelte van die blaardak verminder en die kwantumdoeltreffendheid van blare op die buitenste deel van die blaardak verminder. Geen betekenisvolle effek is op FFV gekry nie. Dit wil voorkom asof die wit laag kaolien op die bome lig weerkaats en veroorsaak dat minder lig na die blaar deurdring. Dit verminder dan die fotsintesetempo. Met die baie warm weer wat in die Wes-Kaap gedurende die tweede seisoen ervaar is, kon die Surround™ behandelings nie sonbrand verhoed nie. Dit wil voorkom asof Surround™ nie 'n baie doeltreffende oplossing in kommersiële boorde sal wees nie. Alternatiewe oplossings, soos byvoorbeeld evaporatiewe verkoeling, sal oorweeg moet word.

Dedicated to my father, Michael, and my mother, Jennifer

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1. LITERATURE REVIEW

CONTROLLING SUNBURN ON POME FRUIT

1.1. INTRODUCTION

Sunburn is a major problem in the fruit industry. The disorder is encountered world-wide, but it is especially prevalent in South Africa where high temperatures are coupled with high irradiation levels. Injury has been reported on many fruit kinds, but pome fruit appears to be particularly sensitive to solar injury (Atkinson, 1971). Damage to apple fruit can amount to 50% of fruit cull in the orchard and up to 10% of the rejections of packed cartons afterwards (Bergh *et al.*, 1980), although this percentage varies greatly from year to year, from cultivar to cultivar and from orchard to orchard. There are also further hidden losses, not observable at harvest, that can be attributed to solar injury. For example, damaged portions of 'Granny Smith' fruit change from white to yellow during storage (Bergh *et al.*, 1980; Hall & Scott, 1989). This yellowing is not acceptable in most markets and these further losses could amount to as much as 3.4% of post-storage carton cull (Bergh *et al.*, 1980). Fruit that has been injured by exposure to high temperatures is also more susceptible to superficial scald (Van den Ende, 1999), a physiological disorder which results in the browning of the skin after fruit has been removed from cold storage (Scott, Yuen & Kim, 1995).

Any cultivation methods that reduce sunburn in the industry are of major importance. In order to find a solution to the problem, it is necessary to understand the phenomenon of sunburn and the factors that cause injury. In this review, the processes that result in the disorder will first be elucidated and thereafter, possible control methods will be discussed.

1.2. SUNBURN

Although sunburn has been studied since the 1920's, it is not yet fully understood (Bergh *et al.*, 1980). Several authors have suggested a number of possible mechanisms that cause the injury, and these, in addition to the observable symptoms, will be reviewed below. Other aspects that will be discussed include factors that improve resistance to injury as well as the various internal mechanisms the plant employs to protect itself from damage.

1.2.1. Observable symptoms

The term "sunscald" has been used in much of the literature to describe the characteristic yellow or brown patch found on the exposed side of affected fruit (Atkinson, 1971). This term has also been used to describe a form of trunk and branch canker thought to be caused by winter freezing (Atkinson, 1971). In order to avoid confusion, the terms "sunburn" and "solar injury" have been adopted in this review, and refer to the injury observed on fruit.

The extent of sunburn differs viz.; sunburn browning and sunburn necrosis. The former is a sub-lethal disorder that initially causes a yellowing of the skin (Hall & Scott, 1989) that later develops into a bronze or brown buckskin appearance on the fruit surface (Schrader, pers. comm.). It is this milder injury that forms the attractive yellow blush that later becomes unacceptably brown following storage (Bergh *et al.*, 1980).

Sunburn necrosis, on the other hand, occurs as a result of thermal death of the fruit surface forming a dark, circular, flattened area (Lockhart & Franzgrote, 1961; Schrader, pers. comm.). In the case of red and blushed cultivars, this blackened area is often surrounded by a narrow inner halo of a greenish-yellow colour and a red or orange-red outer halo (Atkinson, 1971; Schrader, pers. comm.). Cook (1921) pointed out that the exact coloration of the damage will depend on the maturity of the fruit at the time of injury. When first formed, the margin of the affected area is diffuse, becoming more clearly defined with time (Atkinson, 1971). The discoloured area is usually only found on one side of the fruit and will vary in size, depending on the extent of the exposure to solar radiation (Hall & Scott, 1989).

The exact nature of the superficial damage varies between cultivars, but the sub-epidermal damage appears to be similar in all cultivars examined by Moore & Rogers (1943). The dead flesh beneath the surface becomes brown, sometimes very dark, in a sharply defined area that corresponds to the affected surface. The extent of this sub-epidermal damage can be little more than skin deep, or deeper than 15 mm (Moore & Rogers, 1943; Atkinson, 1971). The flesh disintegrates, becoming fairly dry and spongy, and water-core can often accompany the injury (Moore & Rogers, 1943).

Solar radiation can also produce symptoms on leaves. The tissue becomes shiny due to the collapse of epidermal cells, and turns bronze-coloured as a result of the formation of tannins (Lockhart & Franzgrote, 1961). Plants injured by ultraviolet radiation also tend to have thicker and shorter stems. Heat injury has also been observed on exposed bark of trees, resulting in bark necrosis and subsequent cancer formation (Tattar, 1978). Atkinson (1971) claimed, however, that the fruit is the only part of a pome-fruit tree affected by the disorder under the conditions experienced in New Zealand.

1.2.2. Factors that cause sunburn

The disorder is seasonal, frequently observed during hot, dry summers when irradiation levels are high (Atkinson, 1971). Although thought by certain authors to be the result of heat damage alone (Kedar & Retig, 1967), heat does not act in isolation and sunburn on fruit appears to occur as a result of an interaction between various factors (Andrews & Johnson, 1996; Warner, 1997b; Van den Ende, 1999). Heat injury (Tattar, 1978), ultraviolet (UV) light injury (Warner, 1997b), visible light injury (Warner, 1997b), light intensity (Lipton, 1970) and possibly infrared radiation injury (Adegoroye & Jolliffe, 1983; Warner, 1997b) all contribute to the symptoms referred to as solar injury.

In support of these authors, Lipton (1970) found that when he covered half of a tomato fruit with white paint and left the other half exposed, the transition in coloration he observed was distinct, and not gradual. This suggests a light effect, rather than a temperature effect alone. The combination of UV-radiation with sub- or super-optimal temperatures is synergistic and damage by UV is greater than it would be at optimal growing temperatures (Lockhart & Franzgrote, 1961). UV-radiation cannot be the only damaging factor in solar radiation as UV cannot penetrate deeply into the fruit, especially to the corky tissue, where symptoms are sometimes observed (Lipton, 1977).

1.2.2.1. Heat injury

Both extreme temperatures and rapid changes in temperature can cause the heat induced symptoms in fruit (Tattar, 1978). The duration of exposure to these temperatures also plays a role (Adegoroye & Jolliffe, 1983). According to Van den Ende (1999), the temperature of exposed fruit can be 12° to 14°C higher than air temperature, while Unrath (1975) and Parchomchuk & Meheriuk (1996) found that this difference could be between 10-15°C. The critical air temperature threshold at which solar injury occurs, appears to be between 30° and 32°C (Van den Ende, 1999), although this value will clearly vary with changes in environmental conditions. The amount of air circulation around the trees, for example, will affect temperature and so influence the severity of solar injury (Van den Ende, 1999). Heat stress also reduces the rate of red colour development in 'Delicious' apples (Unrath, 1975). Unrath (1975) found that extreme heat resulted in bleached fruit, especially in red cultivars. This may be due to a phenomenon known as solarisation, where oxygen-bleaching of pigments occurs under conditions of extreme irradiation (Salisbury & Ross, 1992).

1.2.2.2. Light injury

As mentioned previously, heat alone is not responsible for the symptoms we refer to as sunburn. Light also contributes to the damage observed; UV light, visible light and possibly also infrared radiation (Adegoroye & Jolliffe, 1983). It is important to note that

UV-radiation is not always destructive, but can in fact stimulate growth at its longer wavelengths (290-320 nm) and at lower intensities (Lockhart & Franzgrote, 1961). It is possible that the growth enhancement observed in this region is simply due to the death of inhibitory pathogens (Lockhart & Franzgrote, 1961). These longer wavelengths are in fact essential for certain biochemical processes, such as the formation of the anthocyanins that produce red colour in pome fruit (Dong *et al.*, 1995). Water present in fruit tissue absorbs infrared radiation and overheats. This may contribute in some degree to solar injury. Adegoroye & Jolliffe (1983) found injury to develop most rapidly in tomato fruits exposed to infrared radiation, as compared with shorter wavelengths.

Damage to plant tissue by ultraviolet radiation occurs by either of two mechanisms; DNA damage, or damage to physiological processes (Lockhart & Franzgrote, 1961; Stapleton, 1992). DNA damage occurs by the absorption of UV by the nucleoproteins in the nucleus (Lockhart & Franzgrote, 1961). They also suggest that excess energy imparted by short-wave UV-radiation results in the formation of peroxides that are toxic to the plant and destroy nucleic material. These authors found that maximum genetic mutations are achieved by exposing plant tissue to UV-C radiation (260 nm). Although UV-C is not a constituent of sunlight, it has been used to study DNA-damage (Stapleton, 1992). Experimental results are cheaper and quicker to obtain than with UV-B radiation sources. Irradiation with UV-C also results in maximum absorption by nucleic acids and peak chlorophyll destruction (Lockhart & Franzgrote, 1961). This suggests that short-wave radiation injures the plant by denaturing nucleic acids that, amongst other functions, control the production of chlorophyll. Lockhart & Franzgrote (1961) hypothesise that DNA damage in leaves is reversible by the process of photoreactivation. Stapleton (1992) confirmed that this is so, but that excision repair is an additional repair mechanism. **Photoreactivation** refers to the reactivation of previously inactivated cells through exposure to visible light (350-450 nm) (Lockhart & Franzgrote, 1961). Beans exposed to excessive UV light developed no symptoms if that period of stress was immediately followed by a daylight period (Bawden & Kleczkowski, 1952). Leaves stressed in the same way but held in the dark, developed severe symptoms. Blue and violet light is much more effective than red light in reducing UV-damage, as it appears to reduce the transparency of epidermal tissue to ultra-violet radiation (Lockhart & Franzgrote, 1961). It also appears that photoreversal requires a large quantity of light in order to be effective (Bawden & Kleczkowski, 1952). **Excision repair** involves the removal of damaged DNA strands, and the re-synthesis of replacement strands (Stapleton, 1992). Other repair strategies may exist in plants, but these are not yet known.

Various physiological responses to UV-B radiation have been observed. These include cell plasmolysis (Lockhart & Franzgrote, 1961), destruction of anthocyanins (although radiation of 290-320 nm can result in the development of anthocyanins), chlorophyll reduction (Caldwell, 1981), destruction of protoplasts and nuclei (Lockhart & Franzgrote, 1961) and reduced leaf differentiation.

1.2.3. Factors that influence resistance to sunburn

The selection of cultivar and rootstock influence the resistance of plant tissue to sunburn. 'Fuji' apples, for example, are especially sensitive to solar injury, especially under hot and semi-arid climates (Parchomchuk & Meheriuk, 1996). 'Granny Smith' is another cultivar that suffers from losses due to solar injury (Nel & Dalton, 1982).

The degree of exposure to direct sunlight can be correlated to the extent of the sunburn damage (Moore & Rogers, 1943; Kedar & Retig, 1967; Adegoroye & Jolliffe, 1983; Parchomchuk & Meheriuk, 1996). The exposure will be determined by the planting density of the orchard and by the position of the fruit on the tree. In higher density plantings, trees are less vegetative than those in conventional orchards. The smaller canopies result in fruit that is more exposed and consequently more susceptible to solar injury. In the southern hemisphere, fruit that is borne on the northern, and especially the north-western, sides of the tree, encounter the highest temperatures, most intense radiation and are most frequently affected by solar injury (Whittaker & McDonald, 1941; Atkinson, 1971).

Age also appears to be an influencing factor; different plant tissues absorb and reflect UV to differing degrees; younger tissues being more sensitive than older tissues (Lockhart & Franzgrote, 1961). Newly planted trees are more susceptible to trunk damage as it takes approximately two years to develop the thicker bark that is resistant to sunburn (Tattar, 1978). However, Cook (1921) reported that sunburn damage was most severe on fruit that was approaching maturity and just beginning to colour.

The interaction of temperature with soil moisture appeared to determine the extent of the temperature damage and so tree water status is an important contributing factor (Tattar, 1978; Van den Ende, 1999). Free water on the fruit surface, on the other hand, does not appear to influence the occurrence of solar injury (Moore & Rogers, 1943).

Certain components of the atmosphere (especially ozone) reduce the UV-content of solar radiation and thus the deeper the layer of atmosphere above the plant, the lower the UV-content of sunlight. It is in this way that the UV-content of solar radiation will be affected by the altitude of the site (Lockhart & Franzgrote, 1961).

1.2.4. Protective mechanisms

Irradiance is essential for the sustainable functioning of plant processes. Photosynthesis, which provides the energy to drive metabolic processes, requires this radiant energy. However, plants can be exposed to too much light, causing an energy overload. The existing protective mechanisms in the plant become saturated and sunburn occurs. An energy overload, as a result of excessive heat shock or high-energy radiation, causes the reduction of oxygen molecules via a multi-step pathway. There is evidence to suggest that no single pathway regulates oxidative stress, but rather that a number of parallel systems may exist in plants (Hausladen & Alscher, 1993). It is these mechanisms that will be discussed here. The intermediate free radicals that are produced are highly reactive and can potentially cause lipid peroxidation, pigment degradation as well as denaturation or mutation of proteins, nucleic acids and lipids (Hausladen & Alscher, 1993; Pallett & Young, 1993). In order to avoid this destructive effect, the surplus energy must be dissipated in some way (Hausladen & Alscher, 1993). Plants that are in environments where they experience oxidative stress, evoke certain cellular responses in order to adapt to this stress.

1.2.4.1 Acclimation

Fruit that is shaded, and then suddenly exposed to sunlight, is much more susceptible to sunburn than fruit that is gradually exposed to increasing radiation as it develops (Atkinson, 1971; Bergh *et al.*, 1980; Schrader, pers. comm.). This would suggest that fruit is able to acclimatise to both high temperatures and high radiation levels. Schroeder (1963) illustrated this phenomenon under *in vitro* conditions using avocado explant tissue. Exposure to a sub-lethal temperature (50°C for 10 min) three days before exposure to temperatures normally found to be lethal (55°C for 10 min), allowed for the accumulation of resistance to heat. This acquired resistance is maintained temporarily and then dissipates to zero approximately three days after maximal heat resistance was attained. This could point to the period of development of protective mechanisms. Thus, pre-treatment with heat induces a protective mechanism that facilitates acclimatisation. Yarwood (1961) reached a similar conclusion after inducing heat tolerance on bean plants both *in vitro* and in whole plants. Lockhart & Franzgrote (1961) report that plants etiolated prior to exposure to UV-radiation are more susceptible to UV-damage than light-grown plants. Without light, etiolated cells and tissues do not develop the competency to react to light (Salisbury & Ross, 1992) and this would suggest that an acclimation period is necessary in order for the plant to cope with higher light levels.

1.2.4.2.The role of photorespiration

Under high temperature conditions, there is a higher ratio of dissolved oxygen to carbon dioxide in the chloroplasts than at lower temperatures. This results in a greater fixation of oxygen by rubisco, thus increasing photorespiration. Photorespiration provides a means of removing excess ATP and NADPH, as they are both needed to regenerate ribulose-1,5-bisphosphate (RuBP) from 3-phosphoglyceric acid (3-PGA) formed during oxygen fixation (Salisbury & Ross, 1992)

1.2.4.3. Antioxidants

The resistance of cells to oxidation can be correlated to antioxidant levels in cell components, and this suggests that antioxidants are involved in consuming excess energy (Hausladen & Alscher, 1993). Amongst these are various phenolics, nucleic acids, proteins, vitamins and flavonols, which all function to absorb excess UV radiation. Carotenoids, on the other hand, reflect UV-radiation (Lockhart & Franzgrote, 1961). The increase in antioxidant levels requires the induction of proteins whose expression is gene regulated. This gene expression may possibly be triggered by the production of glutathione in the stroma (Hausladen & Alscher, 1993).

1.2.4.3.1. Glutathione

One of the destructive free radical intermediates in the reduction pathway of oxygen is the superoxide anion (O_2^-) (Hausladen & Alscher, 1993). O_2^- is removed by the enzyme superoxide dismutase (SOD) and this reaction results in the production of hydrogen peroxide (H_2O_2) which is in itself toxic. H_2O_2 can have two potentially damaging results; it can either inactivate sulphydryl-containing enzymes or it can react with remaining superoxide to form the even more toxic hydroxyl radical. Thus, hydrogen peroxide must be removed from the cell, and successive oxidation and reduction of ascorbic acid, glutathione and NADPH achieve this. This cycle must rapidly come into operation because one of its essential enzymes, ascorbate peroxidase (AP) is in fact inhibited by H_2O_2. This glutathione-ascorbate cycle occurs in both the cytosol and the chloroplasts, and appears to function in conjunction with α-tocopherol, a free radical scavenger in the thylakoid membranes. Glutathione has been shown to protect membrane liposomes from free radical damage (Hausladen & Alscher, 1993).

1.2.4.3.2. Ascorbate

In addition to functioning as an antioxidant that reacts with hydrogen peroxide and a variety of free radicals, ascorbate (vitamin C) may have significant metabolic importance (Foyer, 1993). In accordance with the purpose of this review, only its role as an antioxidant will be discussed. Ascorbate functions as the terminal electron donor in the processes that scavenge H_2O_2, the superoxide anion and the hydroxyl radicle. In addition to this direct antioxidant function, ascorbate also plays a role in the production of various other antioxidants including α-tocopherol and zeaxanthin (Foyer, 1993). Ascorbate is found predominantly in the cell wall or apoplast.

1.2.4.3.3. Carotenoids

In addition to the photoscavenging cycle which involves glutathione and ascorbate, carotenoids also have an important role to play as photoprotective agents (Pallett & Young, 1993). The carotenoids, ß-carotene and one of its derivatives, xanthopyll are found in the thylakoid membranes of the chloroplasts. ß-carotene occurs principally in the core complex of photosystems I (PSI) and II (PSII). Carotenoids function as light harvesting complexes (LHCs) when atmospheric oxygen levels are low, but have the additional benefit of acting as antioxidants as oxygen levels rise (Pallett & Young, 1993). Carotenoids such as ß-carotene interact with superoxide and other free radicals in order to prevent potentially lethal degradation of certain cellular components. The composition of carotenoids in chloroplasts varies between sun- and shade-adapted plants. There is a higher concentration of xanthophyll in shade plants due to the increased LHC activity. Although other factors, such as salt stress, are also involved, high irradiance is probably the most important factor responsible for the production of ß-carotene (Grobbelaar, 1995; Phillips *et al.*, 1995).

1.2.4.4.The xanthophyll cycle

Another protective mechanism employed by the plant in order to dissipate excess energy involves zeaxanthin. The formation of zeaxanthin is regulated by the xanthophyll cycle, and capacity for its formation increases with exposure to excess light (Demmig-Adams & Adams, 1993). Excess light levels stimulate the production of β-carotene of which zeaxanthin is a derivative. Xanthophylls generally accumulate in the chloroplasts and are integral to the thylakoid membrane. The xanthophyll cycle occurs in the LHCs of both PSI and PSII (Pallett & Young, 1993). Peak activity of the xanthophyll cycle appears to occur during conditions of maximum photosynthetic photon flux density (PPFD) (Demmig-Adams & Adams, 1993). It involves the rapid interconversion of three xanthophylls; violaxanthin, antheraxanthin and zeaxanthin in response to changes in light levels. Under conditions of limiting light, violaxanthin is present in high concentrations, while an increase in the incident PPFD will cause zeaxanthin to become predominant (Demmig-Adams & Adams, 1993).

1.2.4.5.Heat shock proteins

According to Burke & Orzech (1988), heat shock causes enzyme inactivation and nucleic acid cleavage. These processes are potentially damaging to the plant, and thus there are several protective mechanisms. One of them involves the production of heat-shock proteins (HSPs). These HSPs are not only developed in response to heat stress, but also in response to water stress, excess metals in the cytoplasm and in the presence of sulphydryl reagents (Burke & Orzech, 1988). Immediately after these stresses are experienced, their synthesis is induced, and simultaneously, there is a decline in the synthesis of normal proteins. This synthesis is gene regulated. When tissues are returned to their optimal temperatures, HSP production ceases, although the existing proteins are still fairly stable (Kimpel & Key, 1985). The degree of the response to the stress factor will depend on (a) the magnitude of the temperature stress, (b) the degree of the inhibition of the 'normal' protein synthesis and (c) the duration of HSP production. Specific HSPs have specific locations within the cell, typically the nucleus, mitochondria, chloroplast, endoplasmic reticulum and plasma membrane. The exact function of HSPs is unknown but Burke & Orzech (1988) propose a hypothesis that states that an increase in temperature results in a decreased efficiency of the membrane pumps across the tonoplast and plasma membranes. This in turn causes an accumulation of calcium and other metal salts in the cytoplasm. All other stress factors (water stress, etc.) appear to affect this salt accumulation in the cytoplasm. An increase in the calcium concentration of the cytoplasm results in the formation of the calmodulin complex that plays a role in the multi-step activation of certain enzymes (e.g. phospholipase D). This could account for the loss of integrity of the phospholipid membrane of the endoplasmic reticulum that is observed under heat stress conditions.

The accumulation of metals can result in levels that are toxic for the plant and thus these metals are removed by glutathione and phytochelatins. The chelating proteins combine with the noxious metal and aid in its removal from the cytoplasm. Once the metal has been removed, HSPs become proteolysed. The possibility of proteolysis could explain why HSPs do not accumulate significantly following heat treatments, yet they (HSPs) have been shown to accumulate in field situations where heat stress is accompanied by water stress and tissue dehydration. This dehydration causes an increase in cellular concentration and consequently an increase in cytoplasmic metal concentration that generates the continued need for HSPs, and thus they accumulate for as long as the cytoplasmic concentration continues to increase (Burke & Orzech, 1988).

1.3 POSSIBLE CONTROL MEASURES FOR SUNBURN

It is important to weigh up the possible benefits of sunburn control practices with their possible cost, be they financial or horticultural. The various control methods include the use of reflective particle films, pruning and training systems, overhead cooling and shading. These will be discussed below. Bagging, and the use of fans in the orchard, are also mentioned in the literature, but these methods will not be discussed in detail in this review. Bagging can reduce the incidence of sunburn, especially in young orchards where tree canopies are not fully developed (Andrews & Johnson, 1996). A disadvantage of bagging is that temperatures within the bag can be 3°to 8°F (≈2° to 4°C) higher than the surface temperature of an exposed fruit (Andrews, 1997), which in itself can lead to injury. Renquist, Hughes & Rogoyski (1987) mention that the promotion of air movement by using fans reduces solar injury in raspberries.

1.3.1. Inert particle films

A variety of treatments that provide a physical barrier to solar radiation have been implemented in the past. Initially, the focus of the research was on the use of such compounds as additives in herbicide applications as these compounds were found to reduce cuticle integrity. Later the focus shifted to their use as reflectants and anti-transpirants. Whitewashes (Lipton, 1977) and sunscreen creams (Hall & Scott, 1989) have been shown to be effective. Eveling (1969; 1972) and Eveling & Eisa (1976) found that leaves sprayed with suspensions of inert dusts in distilled water developed chlorotic and necrotic areas below the deposits, most likely as a result of cell desiccation. One of the compounds tested by Eveling (1969; 1972) and Eveling & Eisa (1976) was Stockalite (90% koalinite + 10% muscovite), a compound that has a particle size of less than 5 μm (99% mass) and 1 μm (60% mass). These inert dusts were also found to increase the water loss by leaves, not by means of a chemical effect of soluble compounds in the sprays, but rather due to the physical interaction of the dust particles with the epidermal cuticle. Epidermal permeability was found to increase with an increase in dust concentration and a decrease in particle size. The observed increase in permeability was sustained for up four weeks after the application and was unaltered by the partial removal of particles at a later stage. The kaolinite applications were found to increase foliar transpiration and reduce leaf fresh weight (Eveling, 1969). Further work has been performed by Glenn *et al.* (1999), initially as part of an integrated pest management (IPM) programme. These researchers found that the ideal particle size was between 1 and 2 μm, as this achieves maximal adherence of the mineral particles to insect cuticles.

The raw material in hydrophilic particle film (HPF™) technology is kaolin, and this technology is being developed for fruit production, primarily for insect control. This technology uses chemically inert, non-toxic mineral particles to coat plant surfaces. The particles alter the texture and light reflective nature of the plant surface, making it both unfamiliar and undesirable to arthropods (Glenn *et al.*, 1998a; 1999). Certain insects do not even recognise the trees as potential feeding sites. However, according to J. Mosko (Heacox, 1999), if any insects do feed on the fruit trees, the particles adhere to their bodies and act as a strong irritant. The insects or mites also have difficulty in remaining on the plant surface due to the presence of the particle film and so are unable to feed on or lay their eggs on the fruit trees (Heacox, 1999).

Theoretically the product can also control diseases due to the fact that the film that is formed, is hydrophobic, not allowing any moisture to collect on the plant. Thus the development of any moisture-requiring organisms is prevented. In addition, the particle film barrier prevents disease inoculum from directly contacting the plant surface (Glenn *et al.*, 1999). Although initial trials showed that the product did reduce disease, this is difficult to achieve in the field, because complete coverage is required for effective control. According to D.M. Glenn (Heacox, 1999), the required coverage is just not possible with current sprayer technology.

In addition to insect and disease control, there are also other horticultural benefits associated with this HPF™ technology. The product alleviates heat and water stress in the plant due to its reflective nature (Glenn *et al.*, 2001, Heacox, 1999). This improves photosynthetic rates and thereby increases fruit size in apples. The particles that make up the product are porous and so do not plug up the stomata, but rather allow valuable gaseous exchange to take place (Heacox, 1999). Glenn *et al.* (2001) have also found that single leaf carbon assimilation was increased and canopy leaf temperatures were reduced by particle treatments. Abou-Khaled, Hagan & Davenport (1970) also found that kaolin applications reduced leaf temperatures.

In addition to increased fruit sizes, improved red colour in apples and reduced russeting of 'Golden Delicious' apples have also been observed (Glenn *et al.*, 1998b). According to J. Mosko (Heacox, 1999), sunburn on fruit is also reduced. Fruit set is also increased when the product is applied over the whole season. In order to achieve this, post-bloom applications are very important (Heacox, 1999).

However, research on the product has only been in place for the past three years (Heacox, 1999), and therefore long term effects on production and sustainability, as well on insect and disease populations have yet to be determined.

When it comes to the costs involved, P. Burrows (Heacox, 1999) says that the product is designed to be at least cost-neutral when compared with alternative pest protection. There are also additional hidden benefits to which it is difficult to attach monetary values. These include:

- The horticultural benefits mentioned above.
- There is also no danger of pests and diseases developing resistance to the product, as it provides a physical, rather than a chemical barrier (Heacox, 1999).
- Beneficial organisms, such as lady beetles, are still able to operate well against aphids in treated apple orchards. However, insect populations will obviously be lower on the whole and so fewer beneficial organisms will be required (Heacox, 1999).
- This is also a so-called "environmentally friendly" product that has been approved by the Food and Drug Administration (FDA) in the USA (Heacox, 1999).

1.3.2. Pruning and training systems

Andrews & Johnson (1996) claim that the leaves of a canopy are equally as effective at cooling fruit as shade cloth is, thus emphasising the importance of canopy management in controlling sunburn. According to Warner (1997a), the most cost effective means of preventing sunburn, is by achieving a good balance between tree vigour and optimal tree structure. She claims it is cheaper to do this by manipulating nitrogen levels, than it is to attempt to control sunburn by bags, shade netting or overhead cooling. As far back as 1941, the need for correct pruning methods with regard to sunburn prevention was recognised. Whittaker & McDonald (1941) noted that it was necessary to adopt preventative measures from the time of planting of the tree. This sound advice has been reiterated by Hall & Scott (1989). Previously, trees were headed back as low as possible during the early years (Whittaker & McDonald, 1941), but this is no longer done in South African orchards (Cook & Strydom, 2000).

In South Africa, the current trend is to develop a tree that is pyramidal in shape, in order to optimise light distribution throughout the leaf canopy (Cook & Strydom, 2000). Whip nursery trees are planted and immediately tied to a three-wire support system, which lessens wind damage and reduces sunburn. Whittaker & McDonald (1941) recommended that young trees be whitewashed in order to protect them from sunscald. Once planted, apple trees in South African orchards are trained with a single central leader with four weak scaffold branches (Cook & Strydom, 2000). The trees are not headed back, and pruning is kept to a minimum for the first two years. From then on, thinning is practised in order to facilitate good light distribution. This is maintained in later years by removing the most vigorous fruiting branches from the trunk, according to the three-to-one-ratio rule. This is done after harvest (Cook & Strydom, 2000).

It is important to ensure the stability of the fruit-bearing limbs throughout the season, as movement of the fruit during the season results in greater sunscald damage (Hall & Scott, 1989; Wiese, pers. comm.). This is especially critical on the western and north-western sides of the tree in the southern hemisphere (Whittaker & McDonald, 1941). Fruit that develops under shaded conditions, and is then suddenly exposed to direct sunlight and the extreme temperatures associated with intense radiation, is more susceptible to damage than fruit that has been exposed to direct sunlight throughout the season (Wiese, pers. comm.). Acclimatisation to these extreme conditions appears to be the reason for this. Branch stability can be achieved by bending branches downward to the horizontal (in the case of 'Granny Smith') or to below the horizontal (in the case of cultivars such as 'Fuji' and 'Royal Gala'). Once the branches have been bent they can be held in place by inserting wire stays between the central leader and the laterals (Wiese, pers. comm.). The development of a multi-limbed tree with several tiers, provides protection for the fruit in the form of shading (Whittaker & McDonald, 1941). Tree vigour and sufficient leaf coverage need to be encouraged in order to reduce sunburn, especially when there is a heavy crop load (Van den Ende, 1999). Annual extension-growth of shoots needs to be between 20 and 30 cm, and these shoots need to be well-distributed over the tree in order for the fruit to receive filtered light rather than excessive direct sunlight (Van den Ende, 1999). However, colour development in red and blushed cultivars is dependant on exposure to sunlight (Atkinson, 1971) and more shade generally means less colour, especially in red-skinned cultivars (Warner, 1997b). Also, heightened vegetative vigour results in lower yields. The density of the foliage must therefore be carefully managed in order to achieve a balance between fruit protection and optimal fruit coloration and yield (Atkinson, 1971; Warner, 1997b).

The hybrid tree cone (HYTEC) training system was developed for arid apple-producing areas, where sunburn can be a serious problem (Barritt, 1992). The HYTEC system is designed to produce high quality fruit with improved size, excellent colour and finish and most importantly, a reduced incidence of sunburn. The HYTEC pruning system produces individual cone-shaped, 3-meter-tall central leader trees. They are planted at medium to high densities in single rows on dwarfing rootstocks with a tree support system. In terms of both tree form and pruning and training, the hybrid tree cone has a hybrid of features of the slender spindle and the vertical axis systems (Barritt, 1992). In this system, various pruning and/or bending techniques are used on the central leader to:

- minimise vigorous growth high in the tree
- reduce the height of the tree
- stimulate lateral branching (Barritt, 1992).

Barritt (1992) recommends either one the following cultural practices to achieve this:

1. Each dormant season, the vigorous top shoot can be removed and a lower, weaker branch tied to the support pole to become the new central leader. The new leader may then be slightly headed in order to stimulate branching.
2. The current central leader can be retained and then simply pruned, either by heading, or by bending it into an oblique or horizontal position. The central leader is pruned and/or bent annually until the tree is 3m high.

Various other methods of controlling sunburn exist, but there is a perception that the most cost-effective solution is to control nitrogen levels in order to obtain a good balance between tree vigour and tree structure (Warner, 1997a). These other methods can, however, be of value in certain conditions and they are therefore discussed below.

1.3.3. Overhead cooling

Three types of overhead cooling exist (Andrews, 1997). **Air** cooling involves the application of low rates of water. This cools the fruit by cooling the surrounding air. **Hydro** cooling involves high application rates of water that remove heat from the fruit as the water runs off. **Evaporative** cooling removes heat from the fruit surface as water evaporates. This latter form of overhead cooling minimises sunburn on fruit most effectively and has the added advantage of requiring minimal quantities of water (Andrews & Johnson, 1996; Faubion, 1998). Reduced fruit temperatures could also improve red coloration (13% additional solid red colour) of the fruit, as Unrath (1975) found that heat stress conditions can reduce the rate of red coloration in 'Delicious' apples. Evans (1993) found this to be especially true if the evaporative cooling is applied around sunrise and just before sundown. Low volume evaporative cooling was found by Unrath (1975) to increase total soluble solids (TSS) by 1%, increase fruit size and reduce bitter pit by 8%. Recasens, Recasens & Barragan (1988) mention that fruit firmness and TSS can sometimes be seen to be reduced by increased irrigation levels, but that this is as a result of an increase in fruit size and is thus a dilution effect. A disadvantage of overhead cooling is the effect it will have on irrigation scheduling and the possibility that anaerobic conditions may develop in the root zone (Evans, 1993; Warner, 1997a).

Kotzé *et al.* (1988) found that solar injury was reduced by up to 50% on spray-cooled 'Granny Smith' and 'Golden Delicious' apples using a pulsed overhead cooling system. They applied water at 6 mm.hr^{-1} through a system of micro-jet sprinklers whenever the air temperature exceeded 28°C. The cycle of a 2 min on-pulse was followed by a 6 to 9 min off-pulse until air temperature decreased to below the set value.

While Kotzé *et al.* (1988) relied on air temperature monitors to activate their system, Parchomchuk & Meheriuk (1996) did not. They found air temperature measurements to be unreliable as air heats more slowly than the fruit. They also found that apples are prone to decay when thermocouples are inserted to measure skin temperature, and therefore they did not rely on fruit temperature monitoring either. To overcome these problems, an artificial sensor was used to simulate the thermal response of an apple surface (Parchomchuk & Meheriuk, 1996).

The installation of evaporative cooling can be an economically viable option in areas where stress conditions are prevalent. Unrath (1975) claims that the cost is justified by the premium prices obtained by early-maturing fruit.

One of the disadvantages of overhead cooling, is the effect it will have on irrigation scheduling and the possibility that anaerobic conditions may develop in the root zone (Evans, 1993; Warner, 1997a). Another disadvantage of this process is that it is adversely affected by the use of poor quality water (Warner, 1997a). Water with a high salt content and pH above 7.8 (Faubion, 1998) leaves behind dissolved salts as it evaporates. These precipitates accumulate to form a hard, chalky deposit on the skin of apples. In severe instances, stalactites start to form on the fruit, especially in the calyx and stem ends. The build-up of these mineral deposits can substantially reduce the quality of the fruit and also increase cleaning costs (Rehrman, 1993). Brushes can help remove the deposits, but are generally only effective on the shoulders of the fruit, and do not reach the calyx- and stem-ends. Deposits also form on the leaves and reduce their photosynthetic efficiency. These deposits can also reduce pesticide efficiency. One possible solution is to reduce the pH to approximately 6.5 (Rehrman, 1993). This can be done by a variety of methods (Warner, 1997c):

- **Sulphuric acid injections** into the water. This method has the advantage of being highly controlled, and no acidification of the soil occurs.

- **Sulphurous acid** can be released into the ground water by burning elemental sulphur. This method usually produces an excess of sulphuric acid, and there is the danger that the soil will become acidified.
- **N-phuric** (mixture of urea and sulphuric acid) can also be applied to the water, but the disadvantage of this method is that it involves the application of nitrogen late in the season.
- **Phosphoric acid**
- **Chelating agents**
- **Gypsum**

Sodium, magnesium and especially calcium carbonates are the most problematic mineral deposits (Rehrman, 1993; Faubion, 1998). According to Dr Bob Stevens of Washington State University, Prosser, silicates, on the other hand, do not contribute significantly to this problem (Faubion, 1998).

1.3.4. Shading

According to Andrews (1997), shading fruit trees can reduce fruit surface temperatures by between 4° and 13°F (≈2° and 7°C), reduce the amount of wind in an orchard, increase the humidity within the canopy, and thus reduce the need for irrigation. Shading will also reduce the amount of intercepted light and the price of the aforementioned advantages is the possible reduction in yield over the long term, especially in areas where light levels are low. Renquist *et al.* (1987) found that UV filters, as well as artificial shading, reduced solar injury in raspberry fruit. Lipton (1977) drew similar conclusions after his experimentation with cantaloupes. Shade cloths reduce UV-B radiation by less than 20%, reduce PPFD that the tree receives by 6 to 8% and reduce the fruit and air temperatures by 1 to 2°C. Schrader (Warner, 1997b) proposes a theory, that the main reason shade cloth reduces sunburn, is not because of the light it filters out, but rather because it diffuses and scatters light, preventing photons from bearing down on a particular spot on the fruit.

One possible problem with overhead shading is that coloration of red and blushed apple cultivars may be reduced. A structure that could be rolled back or removed just prior to harvest could be a solution (Warner, 1997a).

1.4. CONCLUSION

Under the harsh climatic conditions of the Western Cape, sunburn is one of the main reasons for rejection of fruit in apple orchards. The extent of the injury to the fruit ranges from a slight yellowing to a dark, necrotic injury that is susceptible to secondary infection. Cultivar and rootstock selection influence susceptibility to solar injury. Canopy density of the tree also influences the degree of exposure to light and thus influences the incidence of sunburn.

It appears that the disorder results from both high light intensity and high temperature. Fruit is however able to acclimatise to these stressful conditions to a certain extent. Fruit exposed to heat and high irradiation throughout the season is far more resistant to injury than fruit that is suddenly exposed to these extremes. This acclimation ability points to the existence of certain protective mechanisms within the plant. It is only when these systems become overloaded that injury occurs. There is no single protective system, but rather a number of parallel pathways that function to minimise damage. A number of antioxidants are active in some of these processes; most importantly glutathione, ascorbate and various carotenoids. Heat shock proteins are also produced in response to heat stress, although their exact function is unknown.

Aside from the existing defence mechanisms within the plant, there are various cultural practises that can be implemented by the grower in order to minimise losses. Hydrophilic particle film technology (HPF™) utilises foliar kaolin applications to alleviate heat stress and thus possibly improve photosynthetic rates. Increased single leaf carbon assimilation has been reported, increasing fruit size and quality.

Pruning methods aim to develop a leaf canopy that is capable of shading fruit from excess sunlight, but at the same time is able to provide sufficient light for good colour development. This is best achieved by developing a pyramidal tree with a single central leader. It is also important that the lateral branches be stabilised by a support system, in order to prevent the branches from drooping later in the season when the fruit becomes heavier. This movement rapidly exposes previously shaded fruit to sunlight, and causes it to burn.

Evaporative cooling appears to reduce fruit surface temperatures and thereby reduce sunburn. Improved red colour development and better fruit quality are added benefits. In order for this practise to be effective, it is of the utmost importance that the water is of adequate quality. Water can be treated in various ways to improve its quality.

The use of artificial netting has been found to reduce fruit surface temperatures, but a possible disadvantage is the poorer coloration of red and blushed cultivars. The removal of the shade nets prior to harvest may provide an opportunity for fruit to colour up, especially in late-season cultivars.

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2. PAPER 1: EFFECT OF KAOLIN APPLICATIONS ON SOLAR INJURY AND COLOUR DEVELOPMENT IN APPLES

ABSTRACT

M-97-009 (100% kaolin), originally developed for insect control, was evaluated for its efficacy in controlling sunburn on apple. Sunburn is a major problem in the Western Cape and 'Royal Gala', 'Fuji' and 'Granny Smith' apples were evaluated here. In addition to the effect on sunburn, effects on yield, colour development, snout beetle damage and other defects were determined. Sunburn was reduced on all the cultivars tested, although not significantly on 'Granny Smith'. Inconsistent effects on yield parameters were observed, and further trials are needed in order to explain this. The applications significantly increased hue angle on 'Fuji', but this problem may be rectified by improved application techniques. M-97-009 shows promise as a method of controlling sunburn, but further trials are required in order to confirm this.

Keywords: apple, colour development, kaolin, solar injury, sunburn

INTRODUCTION

Sunburn is a major problem in the apple industry worldwide (Figure 1A). In South Africa, damage can amount to as much as 50% of fruit culled in the orchard, and up to 10% of the rejections in the packhouse afterwards (Bergh *et al.*, 1980), although this figure varies greatly from year to year, from cultivar to cultivar and from orchard to orchard. In certain areas, growers believe sunburn to be the foremost reason for rejection of apple fruit, especially for susceptible varieties such as 'Fuji' (Andrews & Johnson, 1996). There are also further hidden losses caused by solar injury that are not observable at harvest. These include the delayed discoloration of sun-damaged fruit during storage of a cultivar such as 'Granny Smith'. A slight blush at harvest becomes brown during storage, causing an unattractive appearance. This fruit is also more susceptible to superficial scald development during storage (Van den Ende, 1999). These latent losses due to sunburn could amount to as much as 3.4% of total storage losses (Bergh *et al.*, 1980). Thus, cultivation methods that can be implemented to reduce sunburn would be of major importance to the producer.

There are a number of possible solutions to the problem. Pruning techniques that allow for adequate leaf-canopy development provide the fruit with shade, thus protecting it from sunburn (Andrews & Johnson, 1996). Training and support systems that encourage the development of sturdy lateral branches, limit movement of branches, thereby preventing fruit from sudden movement that exposes them to the higher light intensities that lead to damage (Cook & Strydom, 2000). Evaporative cooling is another possible solution (Andrews & Johnson, 1996). Kotzé *et al.* (1988) found that solar injury could be reduced by up to 50% by using a pulsed overhead cooling system. Artificial shading effectively reduces solar injury of raspberry (Renquist, Hughes & Rogoyski, 1987) and canteloupe melon (Lipton, 1977), and reduces canopy temperatures in apple (Andrews, 1997). Thus, shading could possibly be effective in reducing sunburn in apple.

The use of kaolin in hydrophilic particle film (HPF™) technology is being developed for fruit production. This technology uses chemically inert, non-toxic mineral particles to coat plant surfaces (Glenn *et al.*, 1998a) (Figure 1B). Originally intended for insect control in integrated fruit production (IFP) systems, the particles alter the texture and the light-reflective nature of the plant surface, making it both unrecognisable and undesirable for certain arthropods (Glenn *et al.*, 1999). In addition, the particle film barrier prevents disease inoculum from directly contacting the plant surface. According to John Mosko, the white kaolin applications also alleviate heat and water stress in the plant, and sunburn is reduced (Heacox, 1999). In addition, fruit size is increased, coloration of red apples is improved and russeting of 'Golden Delicious' apples is reduced (Glenn *et al.*, 1998b).

This paper reports on results of preliminary trials performed to determine the viability of HPF™ technology, specifically M-97-009, in sunburn management under South African conditions.

MATERIALS AND METHODS

Plant material

The trials were carried out on the farm Nooitgedagt in the Koue Bokkeveld area near Ceres in the Western Cape, South Africa (33°12'S; 19°19'E). This is a winter rainfall region of which the annual rainfall is ≈830 mm. Three apple cultivars were evaluated in this trial; 'Royal Gala', 'Fuji' and 'Granny Smith'. Each cultivar was selected for the specific information it would provide on the efficacy of HPF™ technology. 'Royal Gala' was selected to evaluate the effect of M-97-009 on colour development and fruit size, as this cultivar often fails to make the grade in both areas. 'Fuji' was selected because the fruit is sensitive to sunburn and appears to exhibit poor colour development when available radiation is reduced. 'Granny Smith' was selected for its susceptibility to sunburn and also to determine the effect of M-97-009 applications on colour development in a green cultivar. The 'Royal Gala' and 'Fuji' trees on M793 rootstock were planted in 1996. Trees were planted with a 4 x 1.25 m (2 000 trees/ha) spacing with 10% of the trees in the 'Royal Gala' plots being 'Hillierie' cross pollinators. The 'Fuji' trees were interplanted with 'Hillierie' (8.36%) and 'Royal Gala' (4.2%) for cross-pollination. 'Royal Gala' fruit was harvested on 23 February 1999 and 'Fuji' fruit on 7 April 1999. The 'Granny Smith' trees on seedling rootstocks were planted in 1957. The spacing at 6 x 6 m resulted in 278 trees/ha. 'Golden Delicious' was planted as cross-pollinator. Full bloom was on 5 October 1998 and fruit was harvested on 30 March 1999.

Standard pest and disease control measures were implemented in conjunction with the treatments described on all three cultivars. Standard fertilisation and irrigation programmes were followed, and chemical and hand thinning were performed according to standard commercial practices.

Experimental design and treatments

The trial was designed as a randomised complete block with 10 replications for 'Royal Gala' and 'Fuji' and 5 replications for 'Granny Smith'. Two treatments were applied on each of the three cultivars; an unsprayed control and M-97-009 (Engelhard Corporation, NJ, U.S.A.) sprays. The compound was mixed with water at a rate of 3 kg powder per 100 L water and applied at a rate of 2.5 L/tree ('Fuji' and 'Royal Gala') and a rate of 7 L/tree ('Granny Smith'). A sticker (Engelhard M-03) was added to the mixture at a rate of 30 mL per 100 L water. This was then mixed thoroughly and applied to the treated trees by means of a hand-held air blast high-pressure spray (Figure 1C). Spraying commenced shortly after petal drop; on 23 October 1998 in the 'Granny Smith' orchard and on 6 November 1998 in both the 'Fuji' and 'Royal Gala' orchards. Trees were sprayed weekly at first, but as growth rate slowed, they were sprayed fortnightly from mid-December until harvest. 'Royal Gala' received 11 applications, 'Granny Smith' 15 applications and 'Fuji' 14 applications throughout the season. As these were preliminary trials, M-97-009 was applied frequently throughout the season in order to ensure good coverage and achieve a good contrast between the control and the treated trees.

Data recorded

Fruit from the 'Fuji' and 'Royal Gala' trees was harvested at the first commercial harvest dates and the number of fruit per tree was determined. All fruit was brought to the laboratory and the following parameters were recorded: a) fruit size; b) fruit colour using a Nippon Denshoku NR 3000 colorimeter to measure the best coloured portion of the fruit using lightness (L), chroma (C) and hue angle (H) values. A hue angle of 0° denotes a red hue, 90° yellow, and 180° green. Chroma is a measure of the saturation of the hue; the lower the chroma, the "greyer" the colour appears to be. An average of two readings per fruit was taken. The Capespan (Bellville, South Africa) A42 and A45 colour charts were used on the 'Royal Gala' and 'Fuji' apples respectively, to grade both the blushed and shaded sides of each fruit; c) percentages of fruit exportable in terms of colour criteria were determined according to the method used by Capespan. Values on the colour charts mentioned are correlated to the percentage of the surface area that is adequately coloured. An average of the blushed and shaded sides is then determined and this value is used as the threshold value to determine whether the fruit is exportable or not. Average coloration must be above 50% for 'Royal Gala' and above 60% for 'Fuji' in order for the fruit to be exported; d) sunburn was graded on a scale of 0 to 3 in the case of the 'Fuji' apples where 0=no sunburn, 1=yellow 'blush', 2=browning and 3=necrosis

(Figure 1D). With 'Royal Gala' apples, either the presence or absence of sunburn browning or necrosis was indicated; e) russeting was graded according to the Capespan A31 chart on a scale of 1 to 12, where 1 indicates minimal russet and 12 severe russet; f) snout beetle and coddling moth damage was graded by simply noting the presence, or absence, of visible damage on the fruit; and g) apple scab (*Venturia inaequalis*) damage was rated on a scale of 0 to 2 with the 'Fuji' apples, where 0=no damage, 1=presence of olive-coloured spots and 2=presence of raised black lesions (Agrios, 1988). The presence or absence of *V. inaequalis* was recorded for the 'Royal Gala' apples.

The 'Granny Smith' trees were harvested commercially on 30 March 1999. A sample of ten fruit from each replication was brought to the laboratory and fruit colour was determined by colorimeter to measure the greenest portion of the fruit, as described above. The remainder of the fruit was graded on a sample grader in a commercial packhouse where the following parameters were recorded: a) fruit size; b) sunburn damage noted as being acceptable or unacceptable for export purposes; c) snout beetle damage; and d) stem-end russeting.

Statistical analysis

Data were analysed using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) programme (SAS Institute Inc., 1990).

RESULTS AND DISCUSSION

'Royal Gala' Trial

Although the effect of M-97-009 on the average fruit mass was not significant in the 'Royal Gala' apples, the treatment significantly (P=0.0120) increased the number of fruit per tree and thus the total yield per tree (P=0.0167) (Table 1). This increase in fruit number is difficult to explain. Since kaolin was applied after petal drop, this would suggest that the applications prevented fruit drop by some means, but this effect was not found on 'Fuji' or 'Granny Smith'. The M-97-009 applications resulted in fruit that were significantly (P=0.0179) darker, but no other colour parameters were significantly affected (Table 2). The incidence of sunburn damage was significantly (P=0.0034) reduced (Table 3). Snout beetle damage was significantly (P=0.0310) reduced (Table 3), but the M-97-009 applications had no significant effect on stem-end russeting, *V. inaequalis* damage nor on the incidence of coddling moth damage of 'Royal Gala' apples (Table 3).

'Fuji' Trial

In the case of the 'Fuji' apples, the M-97-009 treatments significantly (P=0.0015) reduced average fruit mass, even after adjusting the mass for fruit number, but did not affect total yield (Table 4). The treatment significantly (P=0.0227) reduced the number of fruit exportable in terms of colour criteria (Table 5). The treated 'Fuji' apples had darker fruit (P=0.0034), less saturated colour (P=0.0397) and significantly (P=0.0115) less red hue (Table 5). This was reiterated by the colour chart scores which showed significantly (P=0.0067) less red colour on the blushed side of the treated fruit (Table 5). This poor colour development can be explained by the "speckled" appearance of the treated fruit (Table 5). The hand-held applicators resulted in uneven coverage and a certain amount of run-off, causing the mixture to dry in droplets, and in an uneven film. This seems to have resulted in light exclusion on the patches where the M-97-009 collected, causing a "speckled" coloration of the fruit (Figure 1E). Wilton (1999) has also noticed this effect on 'Fuji'. The "speckling" effect was not observed on either the 'Royal Gala' or 'Granny Smith' fruit, and this difference could possibly be ascribed to the heightened light sensitivity of 'Fuji'. The incidence of sunburn "blush", which appears as a slight yellowing of the fruit surface where the fruit was exposed to direct sunlight, was reduced, but not significantly, however, the browning (P=0.0001) and necrosis (P=0.0024) caused by sunburn were both reduced significantly (Table 6). Snout beetle damage was significantly (P=0.0004) reduced (Table 7). The frequency of the preliminary stage of *V. inaequalis* was significantly (P=0.0280) reduced with the application of the M-97-009 sprays, but the incidence of the advanced stage of the disease, where a black scale becomes visible, was not affected (Table 7).

'Granny Smith' Trial

No effect on fruit mass was observed on the 'Granny Smith' apples (Table 8). The colour of the 'Granny Smith' fruit was more saturated in the case of the M-97-009 treatments, as shown by the significantly (P=0.0238) higher chroma value (Table 8), but no other colour parameters exhibited significant differences. The reduction in sunburn was not significant (Table 9). As the trees were much larger than those selected for the 'Royal Gala' and 'Fuji' trials, the spray-coverage obtained in the upper parts of the 'Granny Smith' trees which are prone to sunburn, was not as satisfactory. The effect of Surround™ on snout beetle damage and stem-end russeting was not significant (Table 9). No *V. inaequalis* or coddling moth damage was observed on the 'Granny Smith' apples. The lack of significant results obtained on this cultivar was possibly due to insufficient M-97-009 coverage as the trees were larger and had denser canopies than those selected for the 'Royal Gala' and 'Fuji' trials.

CONCLUSION

The increase in fruit set observed on M-97-009-treated 'Royal Gala' trees, is difficult to explain. This effect is inconsistent between cultivars, and was not observed on 'Fuji', where a reduction in fruit size was observed. 'Fuji' appears to be more sensitive to reduced light levels than other apple cultivars and the kaolin applications may have reduced available photosynthetic photon flux density (PPFD). This would have reduced photosynthetic rates, lowering the amount of available synthate and reducing fruit size. No effect on fruit size was observed on 'Granny Smith'. A wider range of cultivars should be tested in further trials in order to explain this between-cultivar variation.

M-97-009 shows potential as a means of reducing sunburn of apple fruit, but more detailed information is required. Future trials will need to determine the effect of kaolin applications on light levels within the canopy, on canopy temperatures, photosynthesis and stomatal conductance. The kaolin applications proved to be effective in reducing snout beetle damage, although other effective control measures are available. Inadequate coverage was problematic, both in the 'Fuji' and 'Granny Smith' trials. For future trials, the use of commercial "blowers", which produce a finer spray, and possibly a more even coverage, should be evaluated. This is especially necessary with respect to the "speckle" problem encountered on 'Fuji'. It will also be important to determine if it is possible to remove the kaolin from the fruit with existing packhouse cleaning systems.

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Table 1 Effect of M-97-009 treatment from 6 November 1998 to 19 February 1999 on yield parameters of 'Royal Gala' apples

Treatment		Number (fruit/tree)	Yield (kg/tree)	Average fruit mass[z] (g)
Control		185	22	115
M-97-009		262	30	114
Source	**df**			
Number	1			0.0354
Treatment	1	0.0120	0.0167	0.7671

[z]Means adjusted for covariate (number).

Table 2 Effect of M-97-009 treatment from 6 November 1998 to 19 February 1999 on various colour parameters of 'Royal Gala' apples

Treatment		Lightness (L)	Chroma (C)	Hue angle (H)	Blushed side[z]	Shaded side[z]	Exportable fruit (%)[y]
Control		45.3	51.2	28.4	3	5	93
M-97-009		48.8	47.5	31.1	3	5	92
Source	**df**						
Treatment	1	0.0179	0.5089	0.2606	0.2856	0.9027	0.6399

[z]Average values according to the Capespan A42 colour chart. The lower the value, the redder the colour of the fruit.

[y] Export threshold determined according to standards set by Capespan. Values on Capespan colour chart A42 are correlated to specified percentages of surface area coverage by colour. Average of both sides determined; averages above 50% deemed exportable.

Table 3 Effect of M-97-009 treatment from 6 November 1998 to 19 February 1999 on various defects of 'Royal Gala' apples

Treatment		Sunburn damage (%)	Snout beetle damage (%)	Stem-end russeting[z]	*V. inaequalis* damage (%)	Coddling moth damage (%)
Control		24	10	4	31	2
M-97-009		14	2	4	29	2
Source	**df**					
Treatment	1	0.0034	0.0310	0.9516	0.7123	0.5911

[z]Average values according to the Capespan A31 colour chart. The higher the value, the more pronounced the stem-end russeting.

Table 4 Effect of M-97-009 treatment from 6 November 1998 to 17 March 1999 on yield parameters of 'Fuji' apples

Treatment		Number (fruit/tree)	Yield (kg/tree)	Average fruit mass[z] (g)
Control		60	11	195
M-97-009		73	12	167
Source	**df**			
Number	1			0.0578
Treatment	1	0.3124	0.7640	0.0015

[z]Means adjusted for covariate (number).

Table 5 Effect of M-97-009 treatment from 6 November 1998 to 17 March 1999 on various colour parameters of 'Fuji' apples

Treatment		Exportable fruit (%)[y]	Lightness (L)	Chroma (C)	Hue angle (H)	Blushed side[z]	Shaded side[z]	Speckle (%)
Control		70	40.9	40.5	30.9	4	7	0
M-97-009		55	45.8	38.3	35.7	5	7	79
Source	**df**							
Treatment	1	0.0227	0.0034	0.0397	0.0115	0.0067	0.4512	0.0001

[z]Average values according to the Capespan A45 colour chart. The lower the value, the redder the fruit.
[y] Export threshold determined according to standards set by Capespan. Values on Capespan colour chart A45 are correlated to specified percentages of surface area coverage by colour. Average of both sides determined; averages above 60% deemed exportable.

Table 6 Effect of M-97-009 treatment from 6 November 1998 to 17 March 1999 on sunburn damage of 'Fuji' fruit

Treatment		Sunburn blush (%)	Sunburn browning (%)	Sunburn necrosis(%)
Control		21	21	4
M-97-009		18	7	1
Source	**df**			
Treatment	1	0.6109	0.0001	0.0024

Table 7 Effect of M-97-009 treatment from 6 November 1998 to 17 March 1999 on various defects of 'Fuji' apples

Treatment		Snout beetle damage (%)	Stem-end russetin g[z]	Presence of *V. inaequalis* (%)	*V. inaequalis* with scale development (%)	Coddling moth damage (%)
Control		22	2	25	7	4
M-97-009		6	2	15	7	5
Source	**df**					
Treatment	1	0.0004	0.1804	0.0280	0.7947	0.4826

[z]Average values according to the Capespan A31 colour chart. The larger the value, the more pronounced the stem-end russeting.

Table 8 Effect of M-97-009 treatment from 23/10/98 to 17/03/99 on fruit mass and colour development of 'Granny Smith' apples

Treatment		Average fruit mass (g)	Lightness (L)	Chroma (C)	Hue angle (H)
Control		180	58.2	43.7	115.4
M-97-009		180	59.0	45.0	115.6
Source	**df**				
Treatment	1	0.9808	0.1392	0.0238	0.6002

Table 9 Effect of M-97-009 applications from 23/10/98 to 17/03/99 on various defects of 'Granny Smith' apples

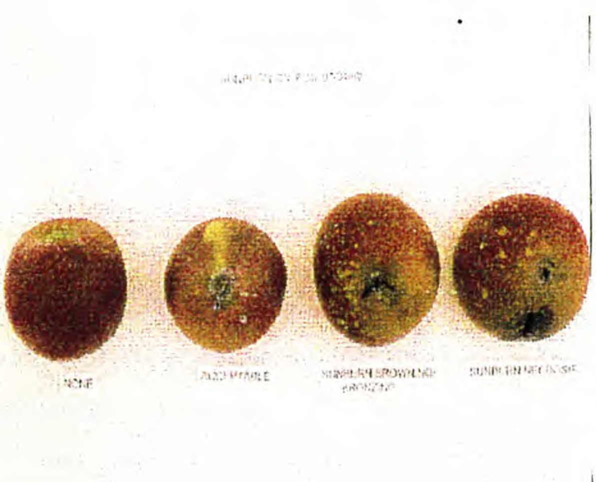
Treatment		Sunburn damage(%)	Snout beetle damage (%)	Stem-end russeting (%)
Control		12	24	59
M-97-009		9	5	72
Source	**df**			
Treatment	1	0.2124	0.1273	0.5279

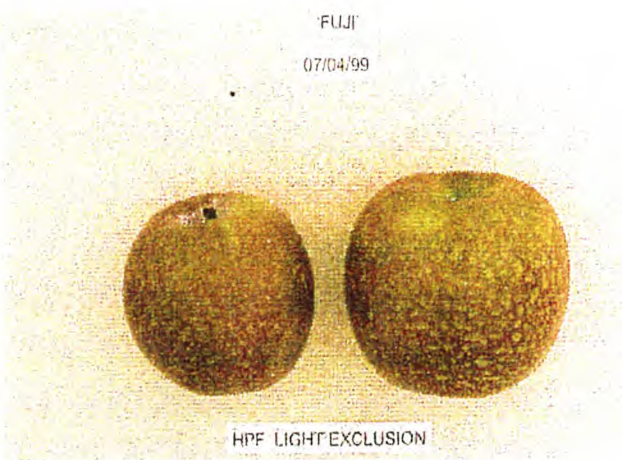
Figure 1 Sunburn on 'Granny Smith' showing flattened necrotic area surrounded by orange-red halo (A); M-97-009 coverage on 'Granny Smith' trees (B); application of M-97-009 by means of hand-held spray (C); sunburn scale used for grading of 'Fuji' (D) and speckled coloration of 'Fuji' fruit (E)


A


B


C




'FUJI'
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HPF LIGHT EXCLUSION

3. PAPER 2: EFFECT OF KAOLIN APPLICATIONS ON SUNBURN AND POME FRUIT QUALITY

ABSTRACT

Surround™ (95% kaolin) was evaluated for its efficacy in controlling sunburn on apple and pear. Further to previous trials conducted with kaolin (Paper 1), additional apple cultivars and 'Rosemarie' pears were included in trials conducted in the Western Cape. In addition to the effect of the product on sunburn, effects on yield, colour development and fruit maturity were determined. In contrast to the previous season, sunburn was not reduced on any of the cultivars examined. Yield parameters were not affected except in the case of 'Royal Gala' where fruit number was increased, and 'Cripps' Pink' where the number of fruit was reduced. Fruit colour was not affected in the apple cultivars, but chroma of 'Rosemarie' pears was reduced, indicating a less intense colour. The Surround™ applications had a variable effect on fruit maturity. Surround™ treatments could not counteract the damaging effects of the high temperatures experienced in the Western Cape this season and was not effective as a control measure for sunburn.

Keywords: kaolin, sunburn, fruit quality, *Malus domestica* Borkh., *Pyrus communis* L.

INTRODUCTION

Sunburn is a major problem in the apple industry worldwide. In South Africa, damage can amount to as much as 50% of fruit culled in the orchard, and up to 10% of the rejections in the packhouse afterwards (Bergh *et al.*, 1980), although this figure varies greatly from year to year, from cultivar to cultivar and from orchard to orchard. In certain areas, growers believe sunburn to be the foremost reason for rejection of apple fruit, especially for susceptible varieties such as 'Fuji' (Andrews & Johnson, 1996). There are also further hidden losses caused by solar injury that are not observable at harvest. These include the delayed discoloration of sun-damaged fruit during storage of a cultivar such as 'Granny Smith'. A slight blush at harvest becomes brown during storage, causing an unattractive appearance. This fruit is also more susceptible to superficial scald development during storage (Van den Ende, 1999). These latent losses due to sunburn could amount to as much as 3.4% of total storage losses (Bergh *et al.*, 1980). Thus, cultivation methods that can be implemented to reduce sunburn in the industry would be of major importance to the producer.

There are a number of possible solutions to the problem. Pruning techniques that allow for adequate leaf-canopy development provide the fruit with shade, thus protecting it from sunburn (Andrews & Johnson, 1996). Training and support systems that encourage the development of sturdy lateral branches, limit movement of branches, thereby preventing fruit from sudden movement that exposes them to the higher light intensities that lead to damage (Cook & Strydom, 2000). Evaporative cooling is another possible solution (Andrews & Johnson, 1996). Kotzé *et al.* (1988) found that solar injury could be reduced by up to 50% by using a pulsed overhead cooling system. Artificial shading effectively reduces solar injury on raspberry (Renquist, Hughes & Rogoyski, 1987) and canteloupe melon (Lipton, 1977), and reduces canopy temperatures in apple (Andrews, 1997) and could possibly be effective in reducing sunburn in apple.

Hydrophilic particle film (HPF™) uses chemically inert, non-toxic mineral particles to coat plant surfaces (Glenn *et al.*, 1998a). Originally intended for insect control in integrated fruit production (IFP) systems, the particles alter the texture and the light-reflective nature of the plant surface, making it both unrecognisable and undesirable for certain arthropods (Glenn *et al.*, 1999). In addition, the particle film barrier prevents disease inoculum from directly contacting the plant surface. According to John Mosko, the white kaolin applications also alleviate heat and water stress in the plant and sunburn is reduced (Heacox, 1999). In addition, fruit size is increased, coloration of red apples is improved and russeting of 'Golden Delicious' apples is reduced (Glenn *et al.*, 1998b). In preliminary trails performed in the Western Cape, kaolin applications were found to reduce sunburn on apple fruit (Paper 1).

This paper reports on results of further trials performed to confirm the viability of HPF™ technology, specifically Surround™, in sunburn management. These trials evaluated additional cultivars and examined fruit quality in greater detail than the preliminary trial.

MATERIALS AND METHODS

Plant material

The trials were carried out in the Koue Bokkeveld area near Ceres (32°58'S 19°19'E) and in the Elgin area near Grabouw (34°11'S; 19°19'E), both in the Western Cape, South Africa. The Western Cape climate is Mediterranean with cool, wet winters and dry, hot summers. The annual rainfall for Ceres is ≈830 mm and ≈1030 mm for Elgin. Five apple cultivars were evaluated on De Rust Estate in Elgin and 'Rosemarie' pears were evaluated on Langrivier in the Koue Bokkeveld. Each cultivar was selected for the specific information it would provide on the efficacy of Surround™. 'Royal Gala' was selected in order to determine the effect of Surround™ on colour development and fruit size, as this fruit is often undersized and poorly coloured. 'Fuji' was selected because the fruit is sensitive to sunburn and appears to exhibit poor colour development when available radiation is reduced. 'Granny Smith' was selected for its susceptibility to sunburn and also to determine the effect of Surround™ on colour development in a green cultivar and 'Golden Delicious' on colour development and the incidence of russet in a yellow cultivar. 'Cripp's Pink' was chosen to determine the effect of the product on a blushed apple cultivar. 'Rosemarie' was selected for its notoriety as a pear cultivar that loses colour under the high irradiation and high temperature conditions experienced just before harvest in the Western Cape.

Standard pest and disease control measures were implemented in conjunction with the treatments described on all cultivars. Standard fertilisation and irrigation programmes were followed, and chemical and hand thinning were performed according to standard commercial practices. Further orchard information is provided in Table 1.

Experimental design and treatments

The trials were designed as randomised complete block designs with 10 replications for each cultivar. Two treatments were used on each cultivar; an unsprayed control and the Surround™ WP (Engelhard Corporation, NJ, U.S.A.) sprays. This is an inert, hydrophilic, white mineral compound consisting of 95% kaolin. The compound was mixed with water at a rate of 7.3 kg/100L and applied at 55 kg/ha on all apple cultivars. For 'Rosemarie' pears, the compound was mixed at a rate of 4.6 kg/100 L water and applied at 55 kg/ha. This was then mixed thoroughly and applied to the treated trees by means of a commercial "blower". Spraying commenced shortly after full bloom; on 20 October 1999 in the 'Rosemarie' orchard and on 27 October 1999 in the apple orchards. The total number of applications for each cultivar are shown in Table 1. Surround™ was applied frequently throughout the season in order to ensure good coverage and achieve a good contrast between the control and the treated trees.

Data recorded

Fruit quality

Fruit was harvested at the first commercial harvest date (Table 1) and the number of fruit per tree was determined. All fruit was brought to the laboratory and the following parameters were recorded: a) fruit mass; b) colour of the blushed side of the fruit using the Capespan (Bellville, South Africa) cultivar-specific colour charts. Colour was scored from 1 to 12, with 1 being well-coloured and 12 being poorly coloured; and c) sunburn was graded on a scale of 0 to 3 in the case of all apple cultivars, where 0=no sunburn, 1=yellow "blush", 2=browning and 3=necrosis (Paper 1). With the 'Rosemarie' pears sunburn was scored from 1 to 12 according to the Capespan P.13 chart, with 1 being no visible damage, and 12 being severe injury.

A sample of 20 fruit was taken from each cultivar and the following external quality parameters were recorded: a) fruit circumference; b) fruit colour using a Nippon Denshoku NR 3000 colorimeter to measure the best-coloured portion of the fruit using lightness (L), chroma (C) and hue angle (H) values. A hue angle of 0° denotes a red hue, 90° yellow, and 180° green. Chroma is a measure of the saturation of the hue; the lower the chroma, the "greyer" the colour appears to be. An average of two readings per fruit was taken; c) stem-end russeting was recorded on 'Fuji' apples using the Capespan colour chart A31 and on 'Golden Delicious' using the A43 chart; and d) 'Golden Delicious' fruit was placed in cold storage until 6 November 2000 and then examined for bitter pit.

Various internal quality parameters were determined on the same sample: a) total soluble solids (TSS) were determined using a N1 hand-held refractometer (Atago, Japan); b) starch conversion was determined with an iodine test and scored according to the Capespan chart for pome fruit; c) titratable acidity (TA), expressed as malic acid content, was determined by titration against 0.1N sodium hydroxide (NaOH), using phenolphthaline as an indicator, or titrations were performed by means of an automated 719S Titrino (Metrohm, Switzerland) along with the accompanying control unit (664), sample changer (674) and pump unit (683). These titrations were performed to an endpoint of pH 8.2; d) seed colour was scored according to the Capespan colour chart and rated from 1 to 6, with 1 being white and 6 being full brown; and e) penetrometer readings were taken on the 'Rosemarie' pears using a FT 327 fruit pressure tester (Southtrade, Italy). An average of two readings was taken; one on the pared, blushed side of the fruit, and one on the pared, shaded side of the fruit.

In order to monitor fruit maturity, weekly samples of 20 fruit were taken from the 'Golden Delicious' trees from 3 February 2000 until harvest on 6 March 2000. Fruit size, fruit colour, seed colour, starch conversion and TSS were determined as described above.

Pigment analyses

Anthocyanin concentration of the peel of 'Rosemarie' pears, and chlorophyll a and b and anthocyanin concentration of 'Cripps' Pink' apples was determined. The blushed side of the fruit was removed using a potato peeler, immediately frozen in liquid nitrogen and then stored at –80°C. Some samples were stored at –20°C due to a space constraint in the –80°C freezer. These samples oxidized, possibly from accidental thawing, and could not be used for analysis. It is therefore recommended that fruit peel be stored at the lower temperature.

After storage, samples were ground in liquid nitrogen using a porcelain mortar and pestle. Once ground, 2 g of the fresh tissue was added to 5 mL cold 100% acetone in a centrifuge tube. Samples were allowed to extract for one hour at 4°C in the dark, while being stirred on an ES5 stirrer (Jankle & Kunkel, Germany). The samples were then vortexed to ensure complete homogenisation, whereafter they were centrifuged for 10 min at 10 000 rpm in a SM-24 rotor of a Sorvall® RC-5B refrigerated superspeed centrifuge (Du Pont Instruments, Newtown, CT, U.S.A.). One mL of the supernatant was pipetted out into quartz cuvettes and absorbance was read at 662 nm and 645 nm on a DU®-64 spectrophotometer (Beckman Instruments, Irvine, CA, U.S.A.). Chlorophyll a and b concentrations were calculated according to Lichtenthaler (1987). The remaining supernatant was decanted into glass vials and the pellets were washed with 5 mL cold acetone, vortexed and centrifuged at 10 000 rpm once more. The resulting supernatant was decanted into the glass vials, combined with the original supernnatant and dried down in a SpeedVac SVC 200H concentrator (Savant, NY, U.S.A.) overnight. The residue was re-dissolved in 2 mL 5% formic acid in methanol and shaken on a KS 500 shaker (Janke & Kunkel, Germany) for ≈30 min until completely dissolved. The solution was then decanted into 4 mL test tubes (Greiner & Söhne, Austria) and centrifuged for 10 min at 5000 rpm in a Minifuge T centrifuge (Heraeus Sepatech, Germany) in order to form a pellet of the remaining cellular debris. Absorbance of the supernatant was read at 530 nm for anthocyanins and at 657 nm in order to correct for chlorophyll (Mancinelli, 1990). Results were quantified against a standard curve of cyanidin 3-galactoside (Apin Chemicals Ltd., U.K.) and expressed as micrograms per gram fresh fruit tissue.

Statistical analysis

Data were analysed using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) programme (SAS Institute Inc., 1990).

RESULTS AND DISCUSSION

'Rosemarie' trial

No yield parameters were affected by the Surround™ applications on 'Rosemarie' (Table 2). However, the applications significantly (P=0.0012) reduced chroma of 'Rosemarie' fruit (Table 3). This would indicate that colour was less saturated on the treated fruit than on the control, although the hue angle was not affected significantly. This difference did not translate into a visual difference in fruit colour, as shown by the colour chart scores (Table 3). The reduced chroma value may be an indication of a reduced pigment concentration in the fruit peel. However, pigment analyses performed on 'Rosemarie' did not provide reliable results as the samples oxidised during storage. Sunburn was not affected by the kaolin applications (Table 4), but incidence of sunburn was low throughout the 'Rosemarie' orchard. Fruit firmness (P=0.0151) and malic acid content (P=0.0323) were both significantly lower in the treated fruit, indicating riper fruit, although TSS did not reflect the same trend (Table 5).

'Royal Gala' trial

In the 'Royal Gala' orchard, the trees treated with Surround™ had a significantly (P=0.0294) higher number of fruit per tree and the fruit was heavier (P=0.0250) than the control, resulting in a significantly (P=0.0156) higher yield on treated trees than on the control (Table 6). Fruit set in 'Royal Gala' was improved by kaolin applications during the previous season (Paper 1), but this effect is difficult to explain. Although fruit was heavier, fruit circumference was not affected (Table 6). This inconsistent result is difficult to explain but uneven thinning in this orchard may have been the cause. Fruit colour of 'Royal Gala' was not affected by the applications (Table 7). Sunburn was not reduced (Table 8); this may be due to the extremely high temperatures experienced, with air temperatures reaching 40°C in the shade in January 2000. Peel temperatures can be 10° to 15°C higher than surrounding air temperatures (Unrath, 1975). No maturity indices were influenced by the kaolin applications (Table 9).

'Golden Delicious' trial

Neither yield (Table 10) nor fruit colour (Table 11) of 'Golden Delicious' was affected by the kaolin applications. Sunburn was not significantly affected (Table 12), and once again, the reason for this may be the harsh summer temperatures experienced in the orchard. No differences in maturity were observed at harvest between control and treated fruit (Table 13), and rate of maturation was not influenced by the Surround™ applications on 'Golden Delicious' apple trees (Figure 1). After 8 months in cold storage, an increased incidence of bitter pit (P=0.0197) was found in the treated fruit (Table 14). This could be due to reduced transpiration rates in both the inner and outer canopies of trees coated with Surround™, and this may have been sufficient to reduce calcium transport to fruit.

'Fuji' trial

The increase in 'Fuji' fruit size observed during the previous season on kaolin-treated trees (Paper 1) was not repeated, and no other differences in yield occurred (Table 15). The "speckled" coloration caused by uneven coverage of the fruit during the previous season (Paper 1) appears to have been prevented by an improved application technique with a commercial "blower", and no effects on fruit colour were observed (Table 16). Due to the extremely high temperatures experienced towards the end of the season, sunburn was a problem, and in spite of the Surround™ applications fruit injury wwas experienced (Table 17). No significant differences in 'Fuji' fruit maturity were found at harvest (Table 18).

'Granny Smith' trial

Surround™ applications had no effect on yield of 'Granny Smith' (Table 19) or on fruit colour (Table 20). As with all cultivars evaluated, sunburn was not reduced by the kaolin applications (Table 21). No differences in maturity were observed between treated and control fruit at harvest (Table 22). The lack of significant effects of Surround™ on 'Granny Smith' is consistent with the results of the previous season although the lack of results the previous season could have been due to inadequate coverage (Paper 1).

'Cripps' Pink' trial

The 'Cripps' Pink' trees treated with Surround™ produced fewer fruit (P=0.0306) than the control trees, although this did not result in a significant reduction in yield (Table 23). Neither fruit size nor fruit mass was significantly affected by the treatments (Table 23). Surround™ had no effect on 'Cripps' Pink' fruit colour (Table 24). These measurements were confirmed by pigment analysis of fruit peel which show no significant differences (Table 25). The incidence of sunburn was not influenced by kaolin coatings (Table 26). Surround™ applications significantly increased (P=0.0060) total soluble solids, indicating riper fruit, although no other maturity indices were affected (Table 27).

CONCLUSION

The increase in the number of fruit per tree, observed on Surround™ treated 'Royal Gala' trees, is difficult to explain. Although this is consistent with the results obtained in the previous season (Paper 1), it contradicts with the results in the 'Cripps' Pink' trial where fruit set was inexplicably reduced. No other cultivars exhibited any effect on yield parameters. Colour development on apples was not influenced by the Surround™ applications, although colour of 'Rosemarie' pears was less intense. Surround™ applications did not reduce the incidence of sunburn, although a reduction was achieved the previous season (Paper 1). This may have been due to the particularly severe weather conditions experienced in the Western Cape this season. The summer temperatures reached 40°C in the shade at times, and it appears that the Surround™ film was not able to protect the fruit from these extreme conditions. Due to the lack of a significant reduction in sunburn during this trial, it is doubtful that the product can be recommended for the control of this disorder under extreme temperatures. Under less severe climatic conditions, the product may prove to be more effective. Treated 'Granny Smith' and 'Golden Delicious' fruit put through a commercial packhouse was difficult to clean. The brush systems were able to remove the kaolin deposits from the fruit cheeks, but kaolin remained in the calyx and stem ends of the fruit (Addendum A). In addition to existing preventative measures, such as tree training systems, it may be worthwhile in the future to evaluate alternative sunburn control measures, specifically evaporative cooling. However, there is still potential for the Surround™ product to be used in integrated fruit production (IFP) systems and organic production as an insect control agent, provided that the residues can be removed from the fruit.

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Table 1 Orchard information for cultivars selected for Surround™ trial

Cultivar	Rootstock	Planting year	Spacing (m)	Cross pollinators	Harvest date	Total number Surround™ applications
'Rosemarie'	BP1	1994	4.5 x 1.5	'Buerre Bosch'	20/01/00	10
'Royal Gala'	seedling	1994	4.5 x 2	'Granny Smith'	24/02/00	14
'Golden Delicious'	M793	1979	4.5 x 2.5	'Topred'	06/03/00	15
'Fuji' (strain 1852)	seedling	1993	4.5 x 2	none	22/03/00	16
'Granny Smith'	seedling	1970	4 x 1.8	none	27/03/00	16
'Cripps' Pink'	M793	1995	3.5 x 1	'Cripps' Red'	12/04/00	17

Table 2 Effect of Surround™ WP applications from 20 October 1999 to 20 January 2000 on production of 'Rosemarie' pears

Treatment		Number (fruit/tree)	Total yield (kg/tree)	Yield efficiency (kg/cm stem)	Averag efruit mass[z] (g)	Fruit circum-ference (mm)	Exportable fruit (%)[y]
Control		220	31	0.93	143	64	78
Surround™		235	35	0.93	152	63	75
Source	**df**						
Number	1				0.0759		
Treatment	1	0.6152	0.3593	0.9523	0.0836	0.6286	0.5845

[z]Means adjusted for covariate (number)

[y]Fruit with circumference of 60-80 mm deemed suitable for export

Table 3 Effect of Surround™ WP applications from 20 October 1999 to 20 January 2000 on colour development of 'Rosemarie' pears

Treatment		Colour chart[z]	Exportable fruit (%)	Lightness (L)	Chroma (C)	Hue angle (H)
Control		10	25	65	43	87
Surround™		10	26	63	40	82
Source	**df**					
Treatment	1	0.8234	0.6019	0.4264	0.0012	0.3401

[z]Average values according to the Capespan P.26 colour chart. The lower the value, the redder the colour of the fruit. Values on a scale of 1 to 12, with 7 or less being suitable for export

Table 4 Effect of Surround™ WP applications from 20 October 1999 to 20 January 2000 on the incidence of sunburn of 'Rosemarie' pears

Treatment		Sunburn average[z]	Exportable fruit (%)
Control		2	86
Surround™		2	85
Source	**df**		
Treatment	1	0.7625	0.7987

[z]Average values according to the Capespan P.13 chart. The lower the value, the less severe the sunburn. Values on a scale of 1 to 12, with a value of 4 or less being suitable for export

Table 5 Effect of Surround™ WP applications from 20 October 99 to 20 January 2000 on various maturity parameters of 'Rosemarie' pears

Treatment		Pressure (kg)[z]	Total soluble solids (% Brix)	pH	Malic acid content (%)
Control		6	12	3.97	0.24
Surround™		5	12	4.09	0.21
Source	**df**				
Treatment	1	0.0151	0.8196	0.0874	0.0323

[z]Pressure readings are the average of both the blushed and shaded sides of the fruit

Table 6 Effect of Surround™ WP applications from 27 October 1999 to 24 February 2000 on production of 'Royal Gala' apples

Treatment		Number (fruit/tree)	Total Yield (kg/tree)	Average fruit mass[z] (g)	Fruit circum-ference (mm)	Exportable fruit (%)[y]
Control		217	16	75	60	72
Surround™		354	29	83	61	82
Source	**df**					
Number	1			0.5957		
Treatment	1	0.0294	0.0156	0.0250	0.1149	0.2521

[z]Means adjusted for covariate (number)
[y]Fruit size larger than 57mm suitable for export

Table 7 Effect of Surround™ WP applications from 27 October 1999 to 24 February 2000 on colour of 'Royal Gala' apples

Treatment		Blushed side[z]	Shaded side[z]	Exportable fruit (%)[y]	Lightness (L)	Chroma (C)	Hue Angle (H)
Control		2	5	93	42	51	25
Surround™		3	5	92	44	49	28
Source	**df**						
Treatment	1	0.2235	0.9580	0.9028	0.1293	0.3308	0.1316

[z]Average values according to the Capespan A42 colour chart. The lower the value, the redder the colour of the fruit

[y] Export threshold determined according to standards set by Capespan. Values on Capespan colour chart A42 are correlated to specified percentages of surface area coverage by colour. Average of worst and best side determined; averages above 50% deemed exportable

Table 8 Effect of Surround™ WP applications from 27 October 1999 to 24 February 2000 on sunburn of 'Royal Gala' apples

Treatment		Sunburn blush (%)	Sunburn browning (%)	Sunburn necrosis (%)	Exportable fruit (%)[z]
Control		11	5	3	81
Surround™		15	4	3	78
Source	**df**				
Treatment	1	0.4972	0.8589	1.0000	0.4679

[z]Fruit with no sunburn damage suitable for export

Table 9 Effect of Surround™ WP applications from 27 October 1999 to 24 February 2000 on maturity indices of 'Royal Gala' apples

Treatment		Starch conversion(%)[z]	Total soluble solids (% Brix)	pH	Malic acid content (%)
Control		50	13	3.73	0.43
Surround™		50	13	3.75	0.46
Source	**df**				
Treatment	1	0.7649	0.3986	0.3679	0.0913

[z]Average values according to Capespan chart for circular pome-type fruit

Table 10 Effect of Surround™ WP applications from 27 October 1999 to 6 March 2000 on production of 'Golden Delicious' apples

Treatment		Number (fruit/tree)	Total yield (kg/tree)	Yield efficiency (kg/cm stem)	Average fruit mass[z] (g)	Fruit circumfer-ence(mm)	Exportable fruit (%)[y]
Control		670	72.1	1.90	106.5	67.7	84
Surround™		713	76.7	1.82	109.2	68.5	93
Source	**df**						
Number	1				0.2637		
Treatment	1	0.3838	0.2911	0.4805	0.4071	0.4058	0.1605

[z]Means adjusted for covariate (number)
[y]Fruit size larger than 57mm suitable for export

Table 11 Effect of Surround™ WP applications from 27 October 1999 to 6 March 2000 on colour of 'Golden Delicious' apples

Treatment		Colour chart[z]	Exportable fruit (%)[y]	Lightness (L)	Chroma (C)	Hue Angle (H)
Control		4	100	69	50	114
Surround™		4	100	70	48	115
Source	**df**					
Treatment	1	0.6607	.	0.1337	0.1599	0.1092

[z]Average values according to the Capespan A28 colour chart. The lower the value, the greener the fruit
[y]Fruit with a colour score of five or less is deemed suitable for export

Table 12 Effect of Surround™ WP applications from 27 October 1999 to 6 March 2000 on maturity indices of 'Golden Delicious' apples

Treatment		Bleaching (%)	Browning (%)	Necrosis (%)	Exportable fruit (%)[z]
Control		17	11	1	71
Surround™		28	16	2	54
Source	**df**				
Treatment	1	0.1639	0.3221	0.6783	0.1546

[z]Fruit with no sunburn damage suitable for export

Table 13 Effect of Surround™ WP applications from 27 October 1999 to 6 March 2000 on maturity indices of 'Golden Delicious' apples

Treatment		Starch conversion(%)[z]	Total soluble solids (% Brix)	pH	Malic acid content (%)
Control		50	14	3.4	0.577
Surround™		40	14	3.4	0.572
Source	**df**				
Treatment	1	0.1446	0.9664	0.3010	0.8527

[z]Average values according to Capespan chart for circular pome-type fruit

Table 14 Effect of Surround™ WP applications from 27 October 1999 to 6 March 2000 on occurrence of bitter pit and stem-end rusetting in 'Golden Delicious' apples

Treatment		Bitter pit (%)[z]	Russet[y]	Exportable fruit (%)[x]
Control		52	5	74
Surround™		72	5	71
Source	**df**			
Treatment	1	0.0197	0.7897	0.7232

[z]Fruit examined for bitter pit after 8 months in cold storage
[y]Fruit scored according to Capespan chart A43. The higher the score, the more severe the russet
[x]Fruit with a rusett score of 6 or less is suitable for export

Table 15 Effect of Surround™ WP applications from 27 October 1999 to 22 March 2000 on production of 'Fuji' apples

Treatment		Number (fruit/tree)	Total yield (kg/tree)	Yield efficiency (kg/cm stem)	Average fruit mass[z] (g)	Fruit circumference (mm)	Exportable fruit (%)[y]
Control		191	26	0.79	136	77	100
Surround™		150	21	0.62	134	76	95
Source	**df**						
Number	1				0.7170		
Treatment	1	0.5030	0.5192	0.4539	0.7754	0.9032	0.3306

[z]Means adjusted for covariate (number)
[y]Fruit size larger than 57mm suitable for export

Table 16 Effect of Surround™ WP applications from 27 October 1999 to 22 March 2000 on colour of 'Fuji' apples

Treatment		Blushed side[z]	Shaded side[z]	Exportable fruit (%)[y]	Lightness (L)	Chroma (C)	Hue Angle (H)
Control		4	8	50	41	36	35
Surround™		4	8	41	43	37	38
Source	**df**						
Treatment	1	0.1964	0.7241	0.3881	0.2492	0.5599	0.3096

[z]Average values according to the Capespan A45 colour chart. The lower the value, the redder the colour of the fruit.
[y]Export threshold determined according to standards set by Capespan. Values on Capespan colour chart A45 are correlated to specified percentages of surface area coverage by colour. Average of worst and best side determined; averages above 60% deemed exportable

Table 17 Effect of Surround™ WP applications from 27 October 1999 to 22 March 2000 on sunburn of 'Fuji' apples

Treatment		Sunburn blush (%)	Sunburn browning (%)	Sunburn necrosis (%)	Exportable fruit (%)[z]
Control		5	15	3	77
Surround™		10	10	2	78
Source	**df**				
Treatment	1	0.1539	0.1685	0.5305	0.6872

[z]Fruit with no sunburn damage suitable for export

Table 18 Effect of Surround™ WP applications from 27 October 1999 to 22 March 2000 on maturity indices of 'Fuji' apples

Treatment		Starch conversion(%)[z]	Total soluble solids (% Brix)	pH	Malic acid content (%)
Control		50	15	3.62	0.49
Surround™		50	15	3.57	0.54
Source	**df**				
Treatment	1	0.8697	0.8300	0.3769	0.2200

[z]Average values according to Capespan chart for circular pome-type fruit

Table 19 Effect of Surround™ WP applications from 27 October 1999 to 27 March 2000 on production of 'Granny Smith' apples

Treatment		Number (fruit/tree)	Total yield (kg/tree)	Yield efficiency (kg/cm stem)	Average fruit mass[z] (g)	Fruit circumference (mm)	Exportable fruit (%)[y]
Control		220	29.7	0.84	137	75	100
Surround™		212	28.5	0.79	133	73	98
Source	**df**						
Number	1				0.7820		
Treatment	1	0.8411	0.8157	0.7870	0.2776	0.1808	0.1679

[z]Means adjusted for covariate (number)
[y]Fruit size larger than 65mm suitable for export

Table 20 Effect of Surround™ WP applications from 27 October 1999 to 27 March 2000 on sunburn of 'Granny Smith' apples

Treatment		Shaded side[z]	Exportable fruit (%)[y]	Lightness (L)	Chroma (C)	Hue angle (H)
Control		4	90	61	46	117
Surround™		4	90	61	47	117
Source	**df**					
Treatment	1	0.5969	0.8402	0.9475	0.6513	0.7739

[z]Average values according to the Capespan A38 colour chart. The lower the value, the greener the fruit
[y]Fruit with a colour score of five or less is deemed suitable for export

Table 21 Effect of Surround™ WP applications from 27 October 1999 to 27 March 2000 on sunburn of 'Granny Smith' apples

Treatment		Sunburn blush (%)	Sunburn browning (%)	Sunburn necrosis (%)	Exportable fruit (%)[z]
Control		33	17	0	50
Surround™		34	21	2	43
Source	**df**				
Treatment	1	0.6857	0.2419	0.1039	0.2376

[z]Fruit with no sunburn damage suitable for export

Table 22 Effect of Surround™ WP applications from 27 October 1999 to 27 March 2000 on maturity indeces of 'Granny Smith' apples

Treatment		Starch conversion(%)[z]	Total soluble solids (% Brix)	pH	Malic acid content (%)
Control		55	13	3	1.09
Surround™		50	12	3	1.14
Source	**df**				
Treatment	1	0.4124	0.2590	0.1272	0.6468

[z]Average values according to Capespan chart for circular pome-type fruit

Table 23 Effect of Surround™ WP applications from 27 October 1999 to 12 April 2000 on production of 'Cripp's Pink' apples

Treatment		Number (fruit/tree)	Total yield (kg/tree)	Yield efficiency (kg/cm stem)	Average fruit mass[z] (g)	Fruit circum-ference (mm)	Exportable fruit (%)[y]
Control		207	23.9	1.08	114	68.3	99
Surround™		169	19.7	0.92	117	68.8	95
Source	**df**						
Number	1				0.5674		
Treatment	1	0.0306	0.0581	0.0814	0.5361	0.5581	0.1708

[z]Means adjusted for covariate (number)
[y]Fruit size larger than 63mm suitable for export

Table 24 Effect of Surround™ WP applications from 27 October 1999 to 12 April 2000 on colour of 'Cripp's Pink' apples

Treatment		Blushed side[z]	Shaded side[z]	Exportable fruit (%)	Lightness (L)	Chroma (C)	Hue angle (H)
Control		4	8	69	52	40	45
Surround™		5	8	68	52	39	47
Source	**df**						
Treatment	1	0.4675	0.8747	0.9251	0.7372	0.5459	0.7475

[z]Average values according to the Capespan P.16 chart. The lower the value, the redder the fruit. Values on a scale of 1 to 12, with a value of 5 or less being suitable for export

Table 25 Effect of Surround™ WP applications from 27 October 1999 to 12 April 2000 on pigment concentrations of 'Cripp's Pink' apple peel

Treatment		Total anthocyanin (mg/ml)	Chlorophyll a (mg/ml)	Chlorophyll b (mg/ml)	Ratio (a:b)	Total chlorophyll (mg/ml)
Control		3.611	12.177	4.399	2.801	16.573
Surround™		5.288	10.893	5.088	2.397	15.981
Source	**df**					
Treatment	1	0.1484	0.3294	0.3229	0.1173	0.7582

Table 26 Effect of Surround™ WP applications from 27 October 1999 to 12 April 2000 on sunburn of 'Cripp's Pink' apples

Treatment		Sunburn blush (%)	Sunburn browning (%)	Sunburn necrosis (%)	Exportable fruit (%)[z]
Control		4	3	1	92
Surround™		6	1	0	93
Source	**df**				
Treatment	1	0.4433	0.0957	0.3434	0.8013

Table 27 Effect of Surround™ WP applications from 27 October 1999 to 12 April 2000 on maturity indices of 'Cripp's Pink' apples

Treatment		Starch conversion(%)[z]	Total soluble solids (% Brix)	pH	Malic acid content (%)
Control		60	13.7	3.31	0.56
Surround™		60	14.1	3.29	0.53
Source	**df**				
Treatment	1	0.6848	0.0060	0.7287	0.2412

[z]Average values according to Capespan chart for circular pome-type fruit

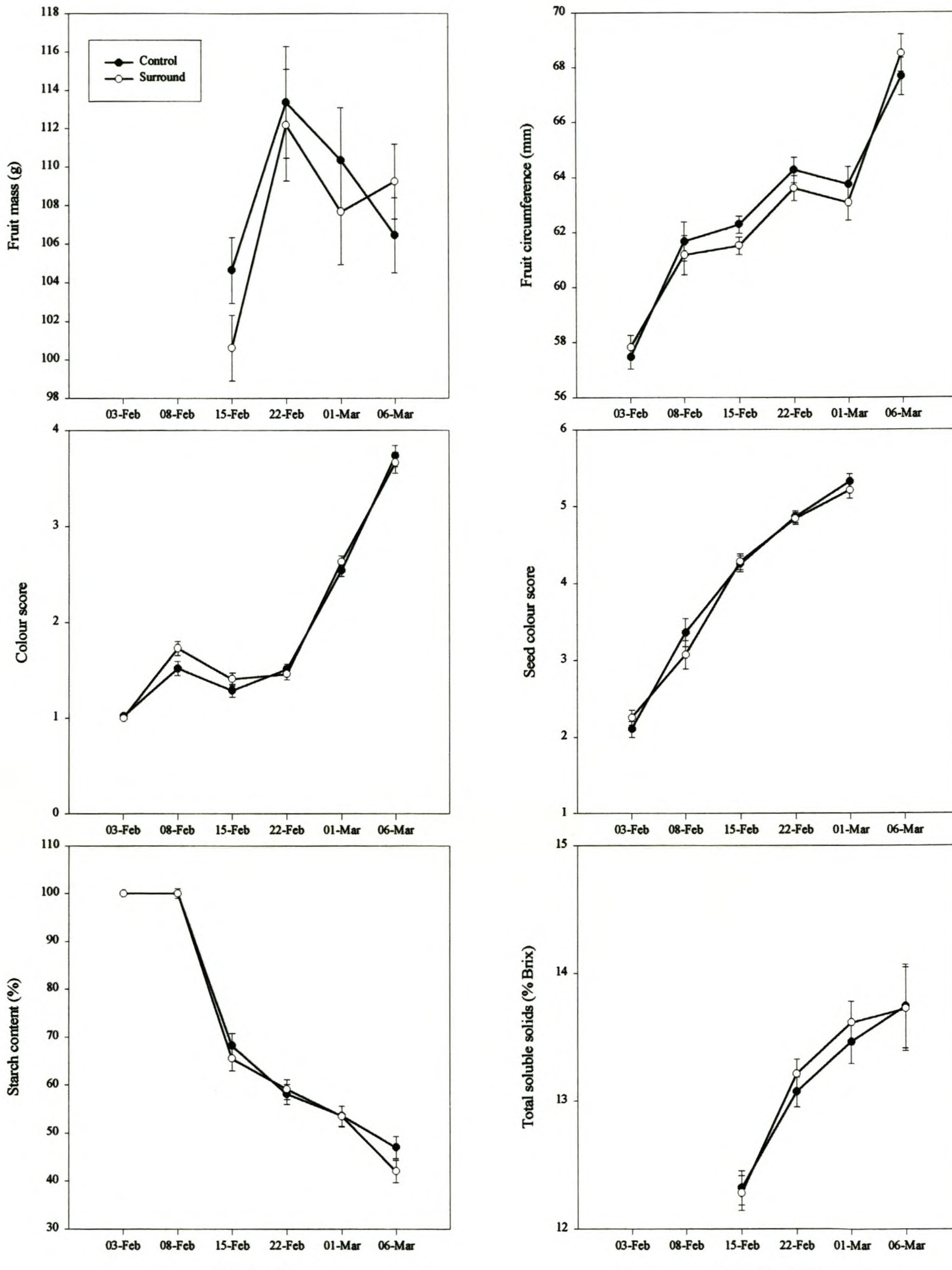

Figure 1 Effect of Surround™ applications on various maturity parameters of 'Golden Delicious' apples sampled from 3 February 2000 until harvest on 6 March 2000

4. PAPER 3: EFFECT OF KAOLIN APPLICATIONS ON GAS EXCHANGE OF 'CRIPPS' PINK' APPLE LEAVES

ABSTRACT

Surround™ WP (95% kaolin) was applied to 'Cripps' Pink' apple trees in the Western Cape in an attempt to reduce sunburn. Further to previous kaolin trials (Paper 1 and 2), the effect of these foliar applications on canopy light conditions, net CO_2-assimilation rate (A), stomatal conductance and transpiration rate was determined. In addition to these spot measurements, photosynthetic light response curves were performed. Measurements were taken on both the inner and outer canopies. The applications significantly reduced A in the inner canopy under both stressful and non-stressful atmospheric conditions, but reduced A in the outer canopy only under non-stressful conditions where stomatal conductance was high. Apparent quantum efficiency (AQE) of leaves on the outer canopy of treated trees was reduced, possibly indicating that coated leaves reflect more light, and thus have less light available for photosynthesis than uncoated leaves under the same external light intensity. No significant effect on photosynthetic photon flux density (PPFD) transmission was found.

Keywords: kaolin, carbon assimilation, PPFD, *Malus domestica* Borkh.

INTRODUCTION

Kaolin has recently been utilised in the development of hydrophilic particle film (HPF™) technology. This technology uses chemically inert, non-toxic mineral particles to coat plant surfaces (Glenn *et al.*, 1998). It has potential benefits for the pome fruit industry and has been found to reduce sunburn and improve fruit size and fruit colour (Glenn *et al.*, 2001). According to John Mosko, the white kaolin applications also alleviate heat and water stress in the plant (Heacox, 1999). Aside from these benefits, Glenn *et al.* (2001) claim that these foliar particle treatments increase single leaf carbon assimilation and reduce canopy temperatures. The majority of trial sites examined by Glenn *et al.* (2001) experienced excessive heat conditions (air temperatures above 30°C). Under such conditions, the kaolin applications appear to reduce temperatures, increasing carbon assimilation and stomatal conductance. However, in one of their trials where midday air temperatures remained below 25°C, leaf carbon assimilation was reduced, due to a reduction in light to the leaf surface (Glenn *et al.*, 1999). Thus, under these conditions, assimilation is limited by low light levels, rather than excessive heat. Abou-Khaled, Hagan & Davenport (1970) found kaolin applications on lemon, orange and *Ficus* plants to reduce leaf temperature and transpiration. Photosynthesis was reduced at low light intensities, but not affected under high light conditions. The kaolinite raised light saturation levels and tended to increase the light compensation points (Abou-Khaled *et al.*, 1970). It would seem that under conditions where all environmental factors, except light, are favourable, that light becomes a limiting factor for kaolin-coated leaves, and photosynthesis is reduced.

In studies conducted in growth chambers, Glenn *et al.* (1999) found no reduction in photosynthetic activity of apple leaves coated with a kaolin product. They also found the particle film to have a neutral effect on leaf photosynthesis of peach trees in the field. In order to assess possible effects of the kaolin applications on carbon balance under South African conditions, photosynthetic photon flux density (PPFD) and gas exchange parameters were examined. Changes in carbon balance could have a bearing on the potential use of Surround™ in commercial fruit production.

MATERIALS AND METHODS

Plant material

The trial was carried out in 2000 in the Elgin area near Grabouw in the Western Cape, South Africa (34°11'S; 19°19'E). This is a winter rainfall region with an annual rainfall of ≈1030mm. The cultivar selected for this trial was 'Cripps' Pink' on M793 rootstock planted in 1995. The orchard was planted with 3.5 x 1m (2857 trees/ha) spacing with 'Cripps' Red' as the cross pollinator. The row direction of the orchard was east-west. Full bloom was on 27 October 1999 and fruit was harvested on 12 April 2000. Standard pest and disease control measures were implemented in conjunction with the kaolin treatments, and standard fertilisation and irrigation programmes were followed. Chemical and hand thinning were performed according to standard commercial practices.

Experimental design and treatments

The trial was designed as a randomised complete block with 7 whole-tree replications. Two treatments were applied; an unsprayed control and Surround™ WP (Engelhard Corporation, NJ, U.S.A.) sprays. The compound was mixed thoroughly with water at a concentration of 7.3 kg/100 L and applied at a rate of 750 L/ha using a commercial "blower" in order to achieve full tree coverage. Spraying commenced on 27 October 1999, shortly after full bloom, and continued until harvest. At the beginning of the season while the trees were experiencing rapid growth, Surround™ was applied at weekly intervals, but as growth rate slowed, trees were sprayed fortnightly from mid-December, and less frequently closer to harvest. In total, 17 sprays were applied during the season.

Canopy light measurements

Light levels in the canopy were measured using a PAR-80 AccuPAR linear PAR/LAI ceptometer (Decagon Devices, Inc., Pullman, WA, U.S.A.). These readings were taken over five whole-tree replicates. The ceptometer was held level at 0.5 m above ground level, measuring PPFD at 1 cm intervals from the trunk over 80 cm toward the outside of the canopy in eight cardinal directions; north, north-east, east, south-east, south, south-west, west and north-west. PPFD readings were expressed as a percentage of above-canopy PPFD. These readings were then averaged across all eight directions at that height for the analysis.

Gas exchange measurements

Net CO_2 assimilation rate (A), stomatal conductance and transpiration rate were measured on two different clear sky days; one a hot day (maximum≈34°C) in mid-February and the other a milder day (maximum≈26°C) late in March. These measurements were taken using a LI-6400 Photosynthesis System (LiCor, Lincoln, NE, U.S.A.) on seven whole-tree replicates. Six leaves per tree were measured individually, three leaves on the outer canopy and three on the inner. Light levels were kept constant for the outer canopy at 1500 $\mu mol.m^{-2}.s^{-1}$ and for the inner canopy at 100 $\mu mol.m^{-2}.s^{-1}$ using the LiCor red/blue LED internal light source. Measurements were taken at ambient temperature and humidity. CO_2 was controlled at an ambient level of 380 $\mu mol.mol^{-1}$ using small pressurised CO_2 cylinders (soda chargers) to ensure constancy.

In addition, photosynthetic light response curves were performed on 30 March 2000 on three whole-tree replicates. Once again, six leaves per tree were measured individually, three leaves on the outer canopy and three on the inner. Light levels were set consecutively at 2000, 1500, 1000, 700, 500, 300, 200, 150, 100 and 50 $\mu mol.m^{-2}.s^{-1}$ using the internal light source. A was plotted against PPFD and the monomolecular function $y=a(1-e^{b-cx})$ (Causton & Dale, 1990) fitted using Statistica (Version 3.0). Using the co-efficients a, b and c, the maximum light-saturated A (A_{max}) (co-efficient a), the light compensation point (b/c) and apparent quantum efficiency (AQE) (ace^{b}) were calculated.

Statistical analysis

Analyses of variance were performed using the GLM (General Linear Models) procedure in the SAS (Statistical Analysis System) computer programme (SAS Institute Inc., 1990).

RESULTS AND DISCUSSION

Canopy light measurements

As shown in Table 1, no significant differences in light interception at 0.5 m (averaged through all eight directions, and from trunk to outer canopy), were observed between control trees and those treated with Surround™. Figure 1 shows light interception in the canopy across the north-south horizontal for the five individual trees, both with and without "sunflecks". Although it is difficult to average and analyse this data and still maintain resolution, data for individual trees are presented here to illustrate the increase in PPFD from the trunk to the outside of the canopy (Figure 1C and D). This however, only measures the diffuse component of light in the canopy. It is possible that coated leaves reflect more light, and thus have less light available for photosynthesis than uncoated leaves under the same external light intensity. Both Glenn *et al.* (1999) and

Abou-Khaled *et al.* (1970) found that a hydrophobic particle film reflects spectral radiance in the visible spectrum, and Abou-Khaled *et al.* (1970) found that increasing kaolin density on leaves reduced transmissivity exponentially.

Gas exchange measurements

There were significant reductions in A in the inner canopy of the trees treated with Surround™ on the milder day (P=0.0056) (Table 2) and on the hot day (P=0.0247) (Table 3). It would appear that these differences between the two treatments become marked under the low light conditions of the inner canopy. In the outer canopies, however, the differences in A are not significant on the hot day (maximum≈34°C) in February, while a significant (P=0.0231) reduction was observed on the milder day (maximum≈26°C) at the end of March. Under very hot conditions, the trees were experiencing stressful conditions and stomatal conductances were strongly reduced compared to the milder day (Table 2 and 3). Thus, the differences between the control and treated trees became less marked. The results obtained on the milder day (maximum≈26°C) are consistent with those obtained by Glenn *et al.* (2001) at their coolest field site (air temperatures below 25°C) on 'Oregon Spur' leaves where carbon assimilation was reduced. The increase in carbon assimilation found by Glenn *et al.* (2001) at hotter sites (air temperatures above 30°C), is not consistent with results obtained on the hotter day in Elgin. Vapour pressure deficit readings confirm the stressful conditions experienced by the trees on the hot day (Table 3). Decreased stomatal conductance of leaves on the inner canopy as compared with the outer canopy resulted in decreased transpiration rates and this led to the higher vapour pressure deficit observed on the inner canopy as opposed to the outer canopy on both days (Table 2 and 3).

The light response curves show no significant differences in A_{max} and light compensation point between treatments, but AQE of the outer leaves was significantly (P=0.0426) lower in leaves treated with Surround™ than on the control (Table 4). It could be that the applications do not have a biochemical effect on leaf functioning, but rather that coated leaves reflect more light, and thus have less light available for photosynthesis than uncoated leaves under the same external light intensity. Abou-Khaled *et al.* (1970) found that white reflecting material applied to leaves decreased the amount of light reaching the chloroplasts. Variation between treated blocks appears to be greater than between control blocks (Figure 2). This may be due to inconsistent foliar coverage by Surround™; well-covered leaves may only reach saturation point at higher light levels than leaves that are poorly covered.

CONCLUSION

The Surround™ applications appear to have resulted in reduced photosynthetic rates at leaf level, perhaps due to greater light reflection. Under the light-limiting conditions of the inner canopy, reflection of light by the Surround™ coating exposed more leaves to unsaturated conditions and thus reduced photosynthesis. Thus the product may reduce long term carbon assimilation in pome fruit trees.

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Table 1 Effect of Surround™ (95% kaolin) applications on average photosynthetic photon flux density (PPFD) of 'Cripps' Pink' 0.5m above ground in eight cardinal directions. PPFD expressed as a percentage of above-canopy PPFD

Treatment		**PPFD (%)**
Control		21.53
Surround™		20.15
Source	**df**	
Treatment	1	0.5842

Table 2 Effect of Surround™ applications on physiological parameters of 'Cripps' Pink'. Measurements were taken on 29/03/2000. Average ambient temperature 26.18°C. Light levels kept constant for outer canopy at 1500 $\mu mol.m^{-2}.s^{-1}$ and for inner canopy at 100 $\mu mol.m^{-2}.s^{-1}$

Position	**Treatment**		**Net CO_2 assimilation ($\mu mol\ m^{-2}\ s^{-1}$)**	**Stomatal conductance ($mol\ m^{-2}\ s^{-1}$)**	**Transpiration rate ($mmol\ m^{-2}\ s^{-1}$)**	**VPD[z] (kPa)**
Outer Canopy	Control		16.4	0.404	4.12	1.12
	Surround™		14.4	0.360	3.93	1.17
	Source	**df**				
	Treatment	1	0.0231	0.0429	0.1395	0.1178
Inner Canopy	Control		3.9	0.201	2.62	1.34
	Surround™		3.1	0.178	2.44	1.37
	Source	**df**				
	Treatment	1	0.0056	0.0518	0.3679	0.4592

[z]Leaf-to-air vapour pressure deficit (VPD)

Table 3 Effect of Surround™ applications on physiological parameters of 'Cripps' Pink'. Measurements were taken on 17/02/2000. Average ambient temperature 34.31°C. Light levels kept constant for outer canopy at 1500 µmol.$m^{-2}.s^{-1}$ and for inner canopy at 100 µmol.$m^{-2}.s^{-1}$

Position	Treatment		Net CO_2 assimilation (µmol m^{-2} s^{-1})	Stomatal conductance (mol m^{-2} s^{-1})	Transpiration rate (mmol m^{-2} s^{-1})	VPD[z] (kPa)
Outer Canopy	Control		15.3	0.246	5.92	2.47
	Surround™		14.2	0.232	5.82	2.65
	Source	**df**				
	Treatment	1	0.3416	0.6710	0.8804	0.3729
Inner Canopy	Control		2.6	0.043	1.48	3.16
	Surround™		1.8	0.047	1.53	3.13
	Source	**df**				
	Treatment	1	0.0247	0.4226	0.7971	0.7789

[z]Leaf-to-air vapour pressure deficit (VPD)

Table 4 Effect of Surround™ applications on light saturated net CO_2 assimilation rate (A_{max}), light compensation point and apparent quantum efficiency (AQE) of 'Cripps' Pink' apple

Position	Treatment		A_{max} (µmol m^{-2} s^{-1})	Light compensation point (µmol m^{-2} s^{-1})	AQE
Outer Canopy	Control		17.15	6.04	0.063
	Surround™		15.80	-1.86	0.043
	Source	**df**			
	Treatment	1	0.6509	0.1797	0.0426
Inner Canopy	Control		9.63	-20.17	0.038
	Surround™		9.51	-3.528	0.035
	Source	**df**			
	Treatment	1	0.9154	0.1537	0.5426

Figure 1 Effect of Surround™ applications from 27 October 1999 to 12 April 2000 on photosynthetic photon flux density (PPFD) (expressed as a percentage of above-canopy PPFD) on 'Cripps' Pink'. The ceptometer was held level at 0.5 m above ground in the leaf canopy. PPFD was measured in a north-south direction at 1 cm intervals where 0 cm=trunk, -80=80 cm north of trunk and 80=80 cm south of trunk. Each colour represents a different whole-tree replicate. Unsprayed control trees (A); Surround™ treated trees (B); control trees with "sunflecks" removed to show base-line PPFD (C) and Surround™ treated trees with "sunflecks" removed to show base-line PPFD(D)

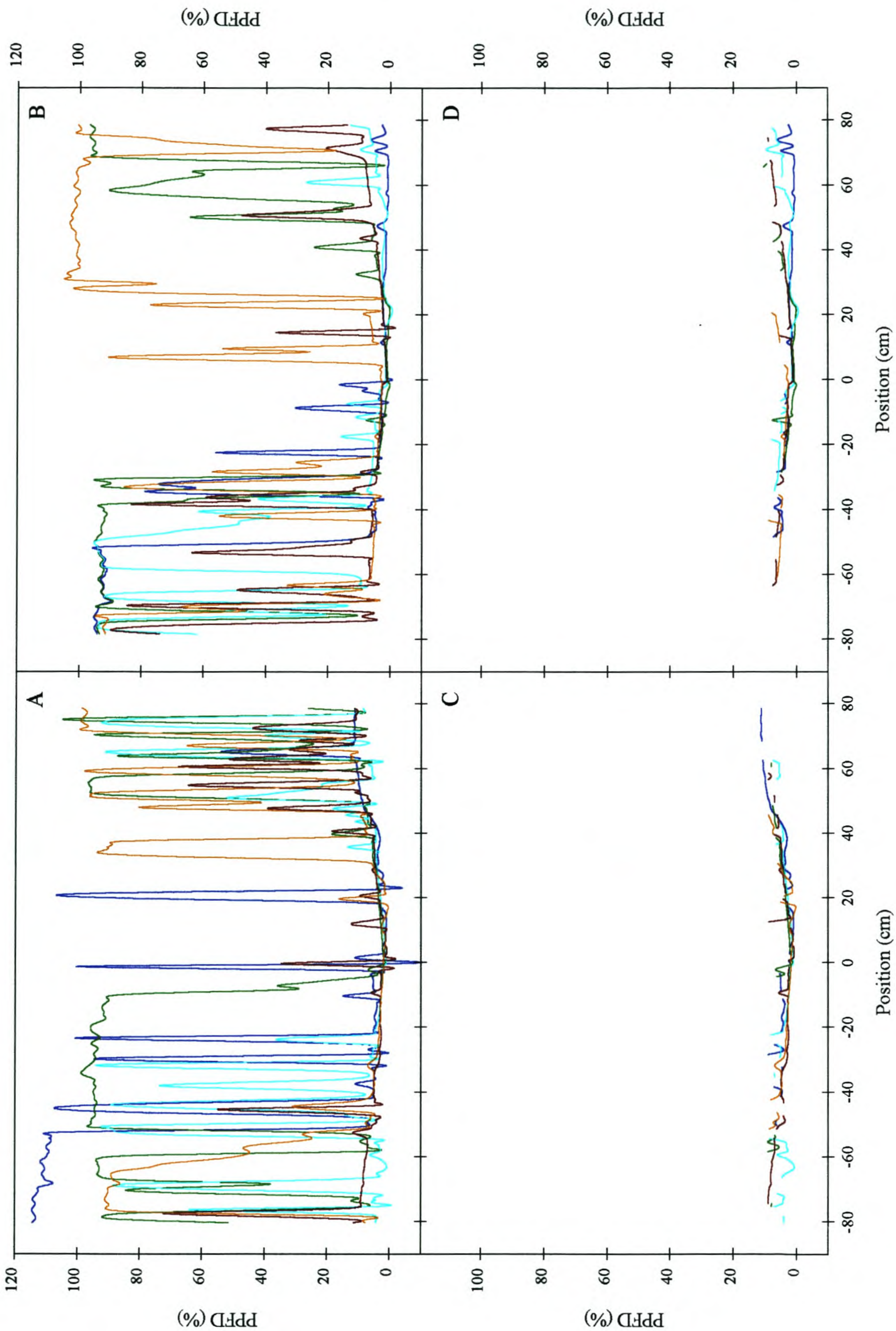
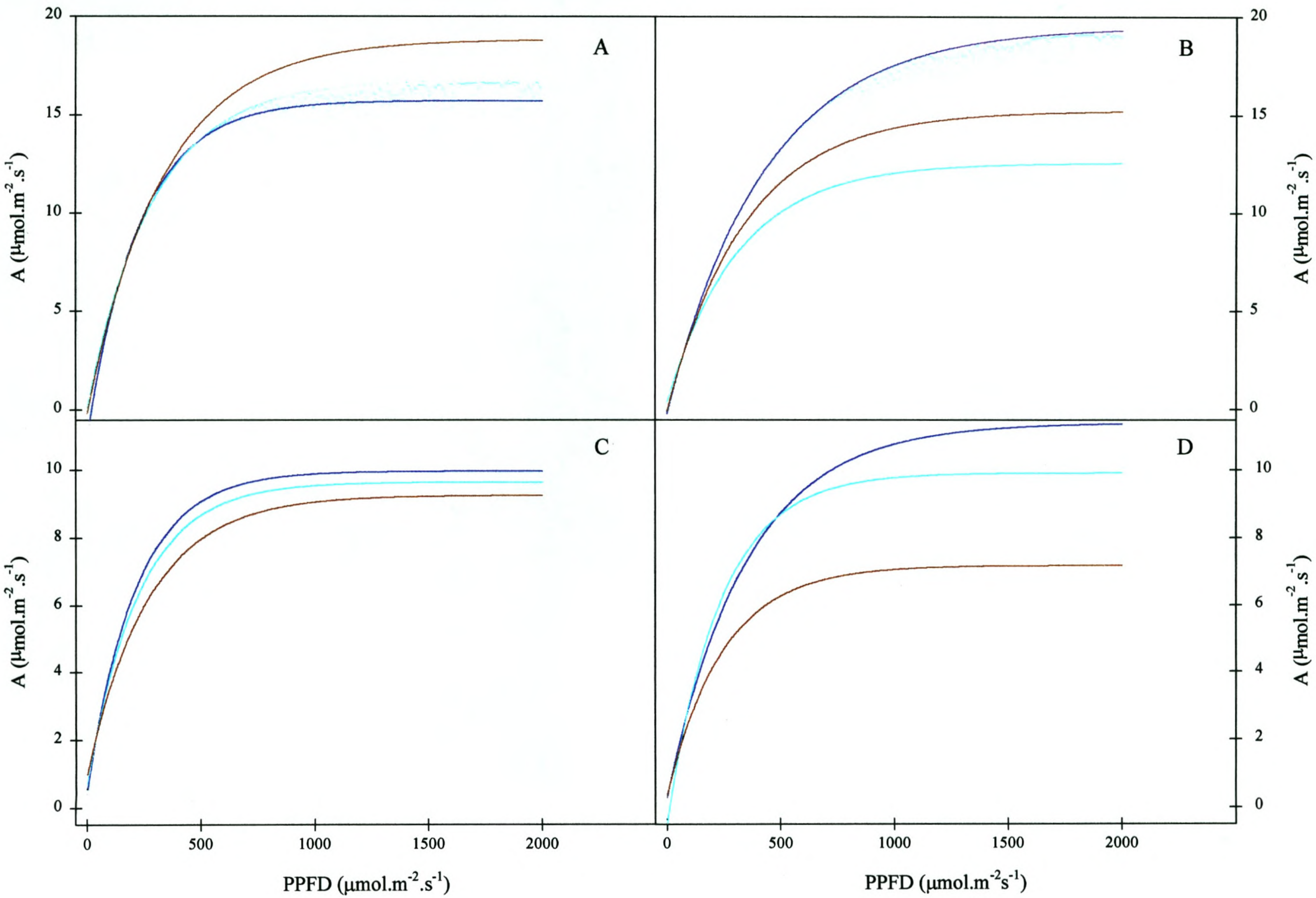

A
B
C
D
PPFD (%)
Position (cm)

Figure 2 Effect of Surround™ applications on relationship between net CO_2 assimilation rate (A) and level of photosynthetic photon flux density (PPFD) of' 'Cripps' Pink' apple. Each curve represents the mean response of three individual leaves for a given tree (=block) for the outer canopy of control trees (A); the outer canopy of trees treated with Surround™ (B); the inner canopy of control trees (C) and the inner canopy of trees treated with Surround™ (D)


A
B
C
D
A (µmol.m-2.s-1)
PPFD (µmol.m-2.s-1)
PPFD (µmol.m-2s-1)
0
5
10
15
20
2
4
6
8
500
1000
1500
2000

5. GENERAL DISCUSSION AND CONCLUSION

Kaolin treatments were applied to pome fruit in an attempt to reduce sunburn, and possibly improve fruit quality. Two formulations were applied; M-97-009 (100% kaolin) during the first season, and Surround™ (95% kaolin) during the second season. During the first season, sunburn was significantly reduced, except in the case of' 'Granny Smith' where the reduction was not significant. As the trees were much larger than those selected for the 'Royal Gala' and 'Fuji' trials, the spray-coverage obtained in the upper, more parts of the 'Granny Smith' trees, which are more prone to sunburn, was not satisfactory. Further application problems were observed on 'Fuji' where a certain amount of run-off occurred, causing the mixture to dry in droplets, and in an uneven film. This seems to have resulted in light exclusion on the patches where the M-97-009 collected, causing a "speckled" coloration of the fruit. This effect was only observed on 'Fuji' and appears to be rectified by application techniques, as it was not observed on 'Fuji' during the second season. Kaolin applications were effective in discouraging snout beetle damage, although other effective control measures are available.

During the second season, Surround™ applications did not reduce sunburn significantly. This may have been due to the particularly severe weather conditions experienced in the Western Cape. The summer temperatures reached 40°C in the shade at times, with fruit peel temperatures being up to 15°C higher than the surrounding air. It appears that the Surround™ film was not able to protect the fruit from these extreme conditions. Under less severe climatic conditions, as experienced during the first season, the product proved to be more effective. Fruit colour was not affected, and the "speckled" coloration observed previously on 'Fuji' was not encountered. The Surround™ applications appear to have resulted in reduced photosynthetic rates at leaf level, perhaps due to greater light reflection. Under the light-limiting conditions of the inner canopy, reflection of light by the Surround™ coating exposed more leaves to unsaturated conditions and thus reduced photosynthesis. Thus the product may reduce long term carbon assimilation in pome fruit trees.

Due to the lack of a significant reduction in sunburn during the second season (Paper 2), it is doubtful that the product can be recommended for the control of this disorder under extreme temperatures. Under less severe climatic conditions, the product may prove to be more effective. There is still potential for the Surround™ product to be used in integrated fruit production (IFP) systems and organic production as an insect control agent, provided that the residues can be removed from the fruit. Treated 'Granny Smith' and 'Golden Delicious' fruit put through a commercial packhouse was difficult to clean. The brush systems were able to remove the kaolin deposits from the fruit cheeks, but kaolin remained in the calyx and stem ends of the fruit. Waxing may reduce the white appearance of the fruit, but this is not permitted on fruit destined for export markets (Addendum A). In addition to existing preventative measures, such as tree training systems, it may be worthwhile in the future to evaluate alternative sunburn control measures, specifically evaporative cooling.

6. ADDENDUM A: OBSERVATIONS OF CLEANING OPERATION OF SURROUND™ TREATED 'GRANNY SMITH' FRUIT IN A COMMERCIAL PACKHOUSE

INTRODUCTION

The raw material in HPF™ technology is kaolin, an inert mineral approved by the Food and Drug Administration in the U.S.A as a food additive (Heacox, 1999). Although safe to consume, any white residues that may remain on the fruit, will discourage potential consumers. Although the application of a wax layer may reduce the white appearance of the kaolin, South African fruit that is exported is not waxed. Thus, 'Granny Smith' fruit that was treated with the kaolin product Surround™ was put through a cleaning line in a commercial packhouse to determine if the treated fruit would conform to these standards.

MATERIALS AND METHODS

Surround™-treated fruit was put through a cleaning line at Kromco (Grabouw, South Africa) after removal from cold storage (Figure 1A). Fruit was first tipped into a water bath, cleaned with an approved detergent, rinsed, placed in a warm water bath, brushed and finally dried (Figure 1B). The brush systems were able to remove the kaolin deposits from the fruit cheeks, but kaolin remained in the calyx and stem ends of the fruit (Figure 1C).

DISCUSSION AND CONCLUSION

Existing fruit-cleaning operations do not appear to remove the Surround™ adequately and regardless of the results obtained in the field, the product cannot be implemented in commercial farming practices if postharvest removal is problematic. There is also concern amongst packers that kaolin deposits in packhouse machinery might be detrimental to the cleaning equipment. However, this aspect was not evaluated.

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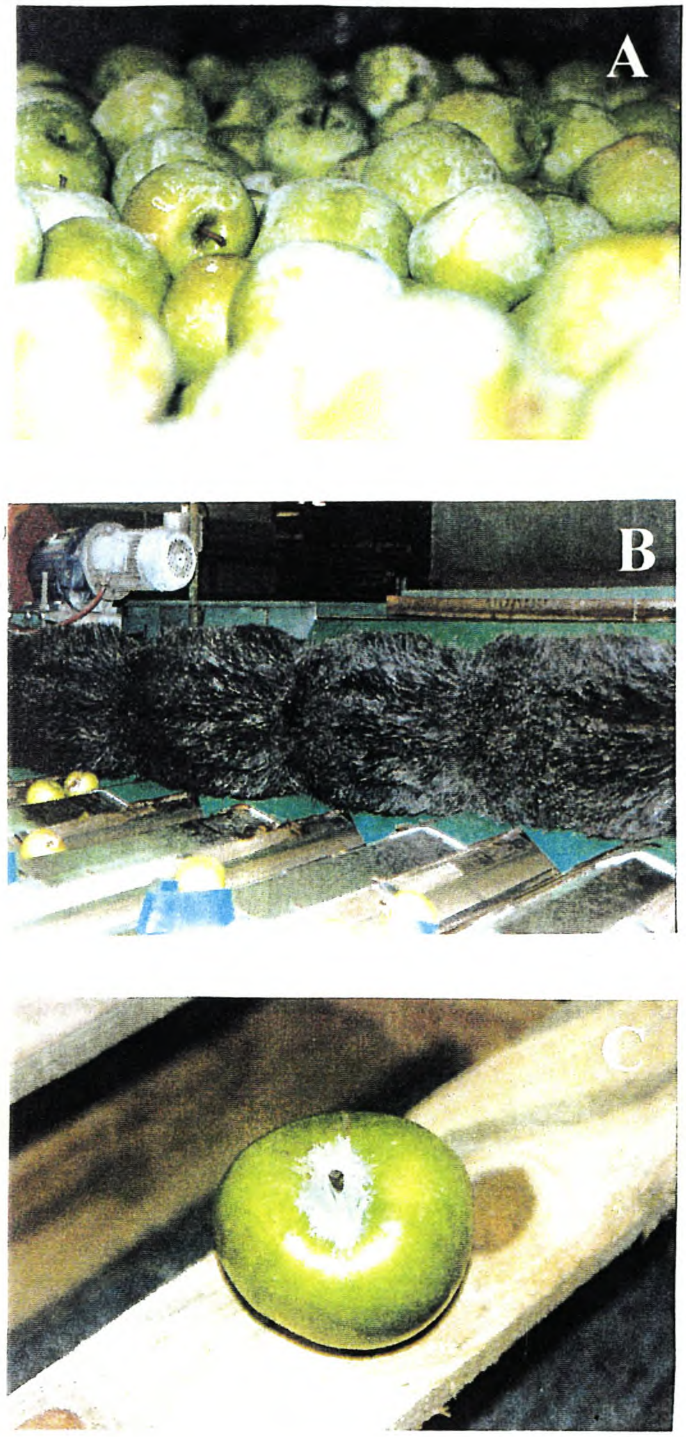

Figure 1 Surround™-treated 'Granny Smith' fruit after removal from cold storage, before cleaning (A); brushes used (B) and kaolin deposits remain in the stem-end of the fruit even once the cleaning and drying process has been completed (C)