Comparative Effects of Evaporative Cooling, Kaolin Particle Film, and Shade Net on Sunburn and Fruit Quality in Apples

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Abstract. We investigated the effects of evaporative cooling (EC), kaolin particle film (KP) and 20% shade net (SN) on the control of sunburn, fruit temperature amelioration and fruit quality of ‘Cripps’ Pink’ and ‘Royal Gala’ apples [Malus domestica Borkh.] under orchard conditions during the 2003–04 season in Stellenbosch, South Africa. On days with maximum air temperatures of 34 to 37 °C, SN fruit were 5.4 to 9.7 °C cooler, EC fruit were 3.1 to 5.8 °C cooler and KP fruit were 1.5 to 6.4 °C cooler compared to the control (nontreated, CO) fruit. SN was effective in reducing fruit temperature from mid-morning until midafternoon; KP was most effective during late morning and early afternoon but not at midday; EC was effective from late morning on days when EC was activated. SN, followed by KP, was the most effective technique for controlling sunburn in fruit of both cultivars, with EC being less effective. The different technologies reduced fruit blush color compared to the CO treatment, with SN showing the most reduction and EC the least. EC increased fruit mass compared to all other treatments in ‘Royal Gala’, and also increased fruit diameter and mass compared to CO in ‘Cripps’ Pink’. We conclude that under the high radiation levels experienced in South African apple production areas, technologies which reduce irradiance as well as fruit temperature (KP, SN) are more effective in reducing sunburn than those which only reduce fruit temperature (EC). However, radiation-reducing technologies are potentially detrimental to color development on blushed apples.

Solar radiation is reported to cause sunburn (solar injury) in various crops (Lipton 1977; Parchomchuk and Meheriuk, 1996; Glenn et al., 2002; Schrader et al., 2003). High solar radiation during the summer results in excessive light and heat load on leaves and fruit. Although the relative contribution of heat and light stresses to sunburn is not yet clearly established, sunburn is caused by the interaction of high temperature and light (Glenn et al., 2002; Schrader et al., 2003). With the continued depletion of the stratospheric ozone layer, the levels of UV-B radiation (280 to 320 nm) reaching the earth’s surface are increasing (Kerr and McElroy, 1993). This, together with global warming associated with fossil fuel emission, indicates a possibility of increasing incidence of sunburn in the future.

Plants use several protective mechanisms to avoid sunburn, e.g., 1) dissipation of excess energy through the xanthophyll cycle (Demmg-Adams et al., 1995; Müller et al., 2001; Ma and Cheng, 2003), 2) induction of antioxidants (e.g., various phenolics, flavonols and proteins) to minimize oxidative damage (Mackerness and Thomas, 1999; Ma and Cheng, 2003; Merzlyak and Solovchenko, 2002; Solovchenko and Schmitz-Eiberger, 2003), 3) UV-B attenuation by UV-B-absorbing/reflecting pigments (Mackerness and Thomas, 1999; Merzlyak and Solovchenko, 2002), and 4) production of heat shock proteins (Burke and Orzech, 1988; Ritenour et al., 2001). The high incidence of sunburn in fruits points to an inadequacy of these mechanisms to prevent the damage.

Fruit are more susceptible to sunburn compared to leaves mainly because they are not endowed with efficient mechanisms of using and/or dissipating solar radiation (Jones, 1981; Blanke and Lenz, 1989). As a result, fruit surface temperature may rise to as high as 10 to 15 °C higher than air temperature (Parchomchuk and Meheriuk, 1996). In South African production areas, the damage due to sunburn on apples can amount to 20-50% of fruit cull in the orchard and up to 10% rejection of packed cartons thereafter (Bergh et al., 1980), although the damage is influenced by such factors as cultivar, climate fluctuations and orchard management practices.

The inadequacy of resistance mechanisms and the high susceptibility of fruit to sunburn would suggest the need for external intervention to suppress sunburn in fruit. Since the 1920s, fruit growers have been looking for ways to avoid sunburn (Bergh et al., 1980). Among the several cultural practices and technologies developed to control sunburn in various crops, evaporative cooling (EC), reflective kaolin-based particle film (KP) and shade net (SN) have been used to reduce sunburn in a wide variety of crops including apples. EC involves an over-tree irrigation system to cool down the fruit when air temperature exceeds a certain threshold. It reduces fruit temperature and sunburn, improves red fruit color in some cultivars and increases soluble solid content (Parchomchuk and Meheriuk, 1996; Unrath, 1972; Unrath and Sneed, 1974). In South Africa, trials carried out on two cultivars of apple (Kotzé et al., 1988) indicate that EC suppressed the incidence of sunburn.

KP is a technology that involves the use of kaolin particles that are reflective to radiation, especially UV wavelengths reaching the surfaces of leaves and fruit, thereby lowering leaf and fruit surface temperatures (Glenn et al., 2002). The positive effects of kaolin for controlling sunburn in various fruit have recently been well documented (e.g., Glenn et al., 2002; Le Grange et al., 2004; Melgarejo et al., 2004; Schupp et al., 2002; Wünsche et al., 2004).

SN involves the attenuation of solar irradiance by shading, thereby reducing temperature and wind velocity and increasing humidity. The application of SN in orchards originated from the ameliorative effect of shade on radiation and temperature observed under natural conditions. Several studies (e.g., Funke et al., 2003; Guerrero et al., 2002; Stamppar et al., 2001; Widmer, 2001) reported the dual use of hail nets for protection from hail storms and sunburn. However, attenuation of solar irradiance may affect color development in red apple cultivars (Funke et al., 2003; Guerrero et al., 2002; Widmer, 2001). Studies on the effects of hail net on apple fruit yield and quality show controversial results. Chen et al. (1998) reported negative impact of hail net on fruit yield and quality; Stamppar et al. (2001) reported no effect of hail net on yield but significantly improved fruit quality while Widmer (2001) and Funke et al. (2003) reported no definite influence of hail net on maturity and quality of apple fruits.

Although EC systems have been used commercially for a number of years in South Africa (Wand et al., 2002), KP and SN are relatively new technologies that are drawing the attention of fruit growers. Yet no comparative studies under the same orchard conditions have been made available to growers for selection of an appropriate method to mitigate sunburn. The objective of the current study was, therefore, to investigate and compare the effectiveness of EC, KP, and SN on fruit temperature amelioration, control of sunburn and effects on fruit quality under the same orchard conditions in South Africa.

Materials and Methods

Study site. A 5-year-old mixed orchard composed of two cultivars of apple (Malus domestica Borkh.), ‘Cripps’ Pink’ and ‘Royal Gala’ at Welgevallen Experimental Farm, Stellenbosch, South Africa (33°55’S; 18°53’E) was used during the 2003/2004 season. The trees were grafted on M793 rootstock and planted with a NE to SW row orientation at spacing of 3.8 × 1.25 m. They were trained as a central leader on a three wire training system. The
trees were irrigated with microjet sprinklers scheduled using neutron moisture probe measurements. No adjustments were made under the EC treatments.

**Experimental design and treatments.** A completely randomized block design with six blocks of ‘Cripps’ Pink’ and six blocks of ‘Royal Gala’ was used. Each block consisted of 20 trees of which two were cross-pollinators and not used. One tree per block per cultivar was assigned to each of the four treatments: evaporative cooling (EC), kaolin-based particle film (KP), shade net (SN) and control (CO). Two to three trees were left as buffers between the treatments to avoid water from the overhead sprinklers of the EC system, or the KP sprays stretching it on the wires and poles used for training the trees. Six percent kaolin-based particle film (Surround WP, Engelhard Corporation, Iselin, N.J.) was first applied on 10 Dec. 2003 and repeated on 16 Jan. 2004 at a concentration of 3%. A surfactant (Agral) was used at a rate of 20 mL/L of water. The whole tree was sprayed from both sides and top for uniform coverage using a hand-held spray apparatus. The volume of spray was 3 ± 0.5 L/tree depending on the tree canopy size. Due to excellent maintenance of coverage it was not necessary to make further applications. No treatments were applied to the control trees.

**Measurements of PPFD, air and fruit temperature.** Seasonal air temperature was monitored using two thermistors attached to an automatic data logger positioned in the orchard (CR10X; Campbell Scientific Inc, Logan, Utah). Seasonal minimum and maximum temperatures are shown in Fig. 1.

The diurnal courses of photosynthetic photon flux density (PPFD), air temperature and fruit surface temperature were monitored on 30 Jan., 10 and 26 Feb. 2004. PPFD under and outside the SN was monitored using a LI-189 quantum sensor attached to a LI-6400 photosynthesis system (LI-COR, Lincoln, Neb.). Air temperature was measured using a digital thermo-hygrometer (SAM990DW). Figure 2 shows the diurnal courses of PPFD inside and outside SN and air temperature on the three measurement days.

The diurnal courses of fruit surface temperature were monitored using an infrared thermometer (Raynger MX 4; Raytek Corp.). Surface temperature measurements were taken on five sun-exposed fruit per tree per treatment at regular intervals during the day. The infrared thermometer was held at a distance of about 0.3 m from the fruit and at an angle of about 150° with respect to the fruit and the sun. Because the emissivity of KP is equivalent to that of plant material (Glenn et al., 2002), emissivity was adjusted to 0.95 for both the KP sprayed and unsprayed fruit. Although measurements were made on the same fruit during the day, measurement spots on the fruit surface changed gradually with the changing angle of the sun.

**Sunburn.** Sunburn was scored on 29 Jan. 2004 and at harvest for each cultivar, using all fruit on the tree, according to a visual detection of exposed fruit surfaces. Fruit with yellowish-brown skin to those with clear necrosis were scored as having sunburn. The amount of sunburn on a tree was expressed as a percentage of the total number of fruit on the tree.

**Fruit quality assessment.** ‘Royal Gala’ fruit were harvested on 11 Feb. 2004 while ‘Cripps’ Pink’ fruit were harvested on 20 Apr. 2004. Forty sample fruit were collected from

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**Fig. 1.** Daily maximum and minimum air temperatures recorded by a weather station close to the experimental orchard during the 2003–04 season. The horizontal line indicates the threshold air temperature for sunburn incidence.

**Fig. 2.** Diurnal courses of photosynthetic photon flux density (PPFD) under shade net and outside shade net, on three days during which diurnal fruit skin temperature was measured. Error bars represent standard errors.
Table 1. Diurnal course of sun-exposed fruit surface temperatures as affected by evaporative cooling (EC), kaolin particle film (KP), shade netting (SN) or control (CO) during the 2003–04 season. Error bars represent standard errors. Mean values for each cultivar followed by different letters are significantly different (LSD test at \( P \leq 0.05 \)).

| Time (HR) | EC          | KP          | SN          | CO          |
|----------|-------------|-------------|-------------|-------------|
| 0830     | 25.4 ± 0.31a| 26.0 ± 0.20a| 24.7 ± 0.25a| 25.8 ± 0.21a|
| 0930     | 37.5 ± 0.35a| 37.5 ± 0.58a| 35.3 ± 0.55b| 39.1 ± 0.34a|
| 1000     | 40.3 ± 0.76a| 42.5 ± 1.04a| 34.4 ± 1.05b| 41.2 ± 0.27a|
| 1200     | 33.6 ± 1.15c| 37.0 ± 0.74b| 36.8 ± 0.21b| 40.7 ± 0.38a|
| 1400     | 35.0 ± 0.54b| 36.9 ± 0.42a| 35.8 ± 0.82b| 38.9 ± 0.40a|
| 1600     | 31.6 ± 1.14ab| 37.9 ± 0.83ad| 34.8 ± 0.47b| 40.0 ± 0.23a|

Fig. 3. Percentage sunburn of ‘Cripps’ Pink’ and ‘Royal Gala’ apple fruit grown with evaporative cooling (EC), kaolin particle film (KP), shade netting (SN) or control (CO) during the 2003–04 season. Error bars represent standard errors. Mean values for each cultivar followed by different letters are significantly different (LSD test at \( P \leq 0.05 \)).

Results

Fruit surface temperature. Fruit under EC treatment had comparable surface temperature to the control fruit over the whole day on 26 Feb. (Table 1). The maximum mean air temperature on that day was 30.6 °C and the EC ran for only 5 min. On the other days, the EC fruit showed significant differences in surface temperature compared to CO fruit only after the onset of overhead irrigation during the late morning and afternoon. Generally, SN markedly reduced fruit surface temperature from midmorning until mid-afternoon, and to a larger degree than EC or KP. KP significantly reduced fruit surface temperature during the late morning and early afternoon, but generally not during midday.

Sunburn. The average incidence of sunburn, as computed from the two recording dates, was 15.2% for ‘Cripps’ Pink’ and 18.6% for ‘Royal Gala’ (Fig. 3). All three technologies used to reduce sunburn showed significant positive effects compared to the CO treatment in both ‘Cripps’ Pink’ and ‘Royal Gala’ apples (Fig. 3). However, the effectiveness of the three technologies differed, with SN being most effective followed by KP.

Fruit color. The hue angles of sun-exposed and shaded fruit surfaces are given in Table 2. Higher hue angle indicates less blush or greener color. Generally, the ranking of the treatments in descending order of sun-exposed surface blush color (hue angle) was CO > EC > KP > SN in both cultivars. In ‘Cripps’ Pink’ KP and SN had significantly reduced blush color compared to CO, although the absolute difference between KP and CO was small. In ‘Royal Gala’ all treatments gave significantly lower blush color than CO, but the EC effect was small. Significant variations in hue angle were also observed for shaded fruit surfaces, being significantly greener (or less blushed) in SN compared to EC, KP and CO fruit in both cultivars (Table 2). EC and KP resulted in less green (or more blushed) skin compared to CO in ‘Cripps’ Pink’ but in ‘Royal Gala’ EC resulted in greener skin compared to CO.

Fruit firmness. The sun-exposed and shaded side flesh firmness of fruit grown under the different sunburn control measures are given in Table 2. In ‘Cripps’ Pink’, SN reduced firmness compared to CO and KP in the sun-exposed side. In ‘Royal Gala’, EC generally increased fruit firmness in both sun-exposed and shaded sides compared to all other treat-
ments. Maximum differences were, however, only about 0.5 kg.

**Starch conversion and TSS.** The starch conversion and TSS of fruit grown under the different sunburn control measures are given in Table 2. All three technologies did not result in any significant effect on starch conversion in both cultivars (Table 2). EC and SN significantly reduced TSS in ‘Cripps’ Pink’ compared to CO and KP, but there were no effects on TSS in ‘Royal Gala’.

**Fruit diameter and mass.** The diameter and fresh mass of fruit grown under the different sunburn control measures are given in Table 2. EC significantly increased fruit fresh mass compared to the other treatments in ‘Royal Gala’, and diameter was increased relative to KP. In ‘Cripps’ Pink’, both EC and KP resulted in significantly higher fruit mass compared to CO, but diameter increases were significant only under EC.

**Discussion.**

The observed temperature difference of 10 to 12 °C between the sun-exposed fruit skin and air temperature at noon and early afternoon clearly show that apple fruit have a high affinity to absorb solar radiation. However, fruit are unable to utilize or dissipate the excess radiation (Blanke and Lenz, 1989; Jones, 1981) which when accumulated would result in rising fruit surface temperature and ultimately localized burning of the fruit skin under hot climates. Although ‘Cripps’ Pink’ and ‘Royal Gala’ are regarded as less susceptible to sunburn compared to other apple cultivars such as ‘Braeburn’ and ‘Granny Smith’ (Palmer et al., 2003), the observed 15% to 19% sunburn during the 2003–04 season was substantial. Maximum daily air temperatures exceeded 35 °C on 4 Jan., 8 to 10 Feb. and 1 Apr. 2003–04 (Fig. 1) which could result in a threshold fruit surface temperature of over 45 °C at which sunburn may occur (Schrader et al., 2003). The major cause of the sunburn might be the heat wave on 4 Jan. 2004 when maximum daily air temperature reached 40 °C (Fig. 1).

The ameliorative effect of EC on fruit temperature observed in the current study agrees with former reports (e.g., Parchomchuk and Meheriuk, 1996; Unrath, 1972; Unrath and Sneed, 1974). However, when radiation is so intense, temperature reductions are not enough that radiation can burn fruit even when evaporating water droplets are on fruit surface. Unlike EC which only reduces fruit temperature via evaporation of water, SN and KP reflect some solar irradiance (including UV-B) in addition to reducing fruit surface temperature (Funk et al., 2003; Glenn et al., 2002; Wünsche et al., 2004). Due to these distinctive effects, sunburn was almost eliminated under the SN treatment and greatly reduced under KP treatment. Study by Le Grange et al. (2004) reported significant reduction in sunburn incidence by KP in ‘Royal Gala’ and ‘Fuji’ during the 1998–99 growing season in South Africa. In the present study, KP effectively reduced sunburn in both cultivars compared to CO and EC (Fig. 3) though it was less effective in ameliorating fruit surface temperature compared to EC. The advantage with KP lies in its ability to reflect the shorter wavelengths which are so injurious to fruit skin. Studies by Glenn et al. (2002) demonstrated that KP is reflective to UV wavelengths reaching the surfaces of leaves and fruit in addition to lowering their surface temperatures.

Although SN was the most effective technique in reducing fruit skin temperature and ultimately sunburn, fruit developed under the SN had very poor blush color development. In agreement with the current study, Stampar et al. (2001); Guerrero et al. (2002) and Funke et al. (2003) reported that hail nets, especially black nets, have reducing effects on fruit skin temperature and sunburn in apple fruit, its negative impact on blush color development in apples. KP, ranking second to SN in controlling sunburn in both cultivars, also reduced the red color of the sun-exposed fruit surface in both cultivars, though not as severely as under SN. Such a negative impact of KP on red color development was also observed in ‘Fuji’ and ‘Honeyscrisp’ (Schupp et al., 2002). However, Glenn et al. (2001) and Wünsche et al. (2004) observed comparable or higher color development under KP compared to untreated fruit but with deep red cultivars. Our results disagree with former reports (Iglesias et al., 2000; Iglesias et al., 2002; Unrath, 1972; Unrath and Sneed, 1974) regarding the improvement of color with EC. Similar to Parchomchuk and Meheriuk (1996) we did not observe significant color differences between EC and control fruit.

The three technologies did not show distinct effects on fruit maturity as indicated by TSS, starch conversion and firmness in both cultivars. The current study agrees with Schupp et al. (2002) who observed no significant effect of KP on TSS and starch degradation patterns in ‘Fuji’, and with Glenn et al. (2001) who observed no significant difference in TSS and firmness between KP treated and untreated fruit of various apple cultivars. Effects of EC and SN on fruit maturity were not consistent in both cultivars. EC improved fruit firmness only in ‘Royal Gala’, which was in agreement with studies on ‘Topred Delicious’ in Spain (Iglesias et al., 2002).

In agreement with a former report (Iglesias et al., 2002; Wand et al., 2002), EC increased fruit size in both cultivars (Table 2) indicating its ameliorative effect on leaves with possible enhancement of photosynthetic rate. Wand et al. (2002) suggested that in response to additional soil moisture and milder atmosphere (lower temperature and higher humidity) under EC, trees respond by keeping their stomata open for increased photosynthesis. Milder atmosphere also minimizes respiratory losses from leaves and fruit, making more carbohydrate available for fruit growth. Although SN may also have comparable effects as EC on the atmosphere around the plant, ‘Royal Gala’ fruit developed under SN were smaller in size compared to those under EC due to the effect of shading on photosynthesis (J. Gindaba, unpublished data). Shading reduces stomatal density, amounts of Calvin-cycle enzymes per unit leaf area, number of chloroplasts per cell, volume of stroma per chloroplast, and stroma-exposed thylakoid membranes, all of which reduce the photosynthetic capacity of the leaf (Lambers et al., 1998). Furthermore, shading may directly reduce the photosynthetic rate of leaves when solar radiation is optimum, as on cloudy days.

Though SN is the most effective technology in reducing fruit skin temperature and sunburn in apple fruit, its negative impact on blush color

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**Table 2.** Color, firmness, starch conversion and total soluble solids, diameter and fresh mass of ‘Cripps’ Pink’ and ‘Royal Gala’ fruit grown with evaporative cooling, kaolin particle film, shade net or control. Significant P values are according to a one-way ANOVA at 95% confidence interval. Mean values in a row followed by different letters are significantly different (LSD test at P ≤ 0.05). Values are mean ± SE (n = 6)

| Fruit quality attributes | Cultivar | EC | KP | SN | CO |
|--------------------------|---------|----|----|----|----|
| Sun-exposed surface color (hue) | ‘Cripps’ Pink | 28.3 ± 0.61bc | 29.8 ± 0.97b | 36.8 ± 1.16a | 27.2 ± 0.59c |
| ‘Royal Gala’ | 36.7 ± 0.89c | 41.1 ± 2.15b | 45.2 ± 1.12a | 32.2 ± 0.53d |
| Shaded surface color (hue) | ‘Cripps’ Pink | 95.7 ± 1.00c | 98.9 ± 1.23c | 104.2 ± 0.70a | 98.4 ± 0.8b |
| ‘Royal Gala’ | 90.9 ± 0.99b | 98.2 ± 1.26a | 96.8 ± 0.96a | 86.5 ± 0.34c |
| Sun-exposed side firmness (kg) | ‘Cripps’ Pink | 8.10 ± 0.08bc | 8.42 ± 0.08a | 8.01 ± 0.08c | 8.29 ± 0.08ab |
| ‘Royal Gala’ | 9.05 ± 0.11a | 8.69 ± 0.11b | 8.77 ± 0.11ab | 8.51 ± 0.09b |
| Shaded side firmness (kg) | ‘Cripps’ Pink | 7.99 ± 0.08a | 8.26 ± 0.08a | 8.05 ± 0.08a | 8.20 ± 0.08a |
| ‘Royal Gala’ | 8.83 ± 0.09a | 8.64 ± 0.10ab | 8.56 ± 0.09a | 8.30 ± 0.09b |
| Starch conversion (%) | ‘Cripps’ Pink | 47.2 ± 2.15a | 48.3 ± 2.04a | 45.1 ± 2.02a | 50.3 ± 2.07a |
| ‘Royal Gala’ | 52.1 ± 3.29a | 54.5 ± 2.94a | 41.4 ± 3.09a | 49.0 ± 2.72a |
| Total soluble solids (%) | ‘Cripps’ Pink | 47.2 ± 2.15a | 48.3 ± 2.04a | 45.1 ± 2.02a | 50.3 ± 2.07a |
| ‘Royal Gala’ | 52.1 ± 3.29a | 54.5 ± 2.94a | 41.4 ± 3.09a | 49.0 ± 2.72a |
| Diameter (mm) | ‘Cripps’ Pink | 63.9 ± 0.40a | 63.7 ± 0.32ab | 63.0 ± 0.33ab | 63.2 ± 0.37b |
| ‘Royal Gala’ | 65.2 ± 0.31a | 62.4 ± 0.36b | 63.2 ± 0.33ab | 63.7 ± 0.39ab |
| Mass (g) | ‘Cripps’ Pink | 114.0 ± 1.84a | 114.6 ± 1.61a | 109.1 ± 1.51ab | 107.9 ± 1.67b |
| ‘Royal Gala’ | 123.8 ± 1.58a | 114.9 ±1.83b | 114.4 ± 1.61b | 117.5 ± 2.04b |
development makes it less useful in commercial farms. Funke et al. (2003) suggested the use of reflective ground cover in the tree alleys under black or white hail nets to effectively enhance fruit coloration. However, this will make the use of SN expensive. Alternatively, nets of lower density (e.g., <15%) may be used to minimize the impact of SN on fruit quality.

Given its lower effectiveness in controlling sunburn, high cost of installation and higher water requirement, an EC system must also be subjected to regular check-ups and monitoring of the quality of irrigation water. Failure of the EC system just for one day may result in a substantial loss depending on the temperature maxima. KP and SN require much less attention compared to EC. However, KP application is less costly compared to the installation of SN structures.

Therefore, if satisfactory fruit quality could not be achieved using SN of lower density, KP could be a good alternative to SN. KP application is easier, cheaper and requires less attention. Removal of the KP deposit at harvest may require additional system for brushing/washing off the residue (Le Grange et al., 2004; Schupp et al., 2002). Such a system has recently been developed for South African apple pack houses, which appears to be successful, but this system is still being tested by the industry. According to Wünsche et al. (2004), a conventional postharvest water bath to remove insects, dust, and other adhering materials can effectively remove KP residues on the fruit surface.

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