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Original Research Paper

Impact of overhead irrigation on fruit quality of 'Scifresh' apples

Daniela Simeone[1], Mauricio Fuentes[1], Javier Sánchez-Contreras[2], Álvaro Sepúlveda[1] and José Antonio Yuri[1*]

[1] Centro de Pomáceas, Facultad de Ciencias Agrarias, Universidad de Talca, Talca, Chile
[2] Departamento de Ciencias Agrarias, Facultad de Ciencias Agrarias y Forestales, Universidad Católica del Maule, Curicó, Chile
[*] Corresponding author: ayuri@utalca.cl; Tel.: +56 71 2200 366

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Abstract: Overhead sprinkler irrigation in orchards modifies the plant microenvironment which can affect fruit quality. The objective of the present study was to evaluate the effect of overhead sprinkler irrigation on fruit sunburn incidence, coloration, maturity parameters and the development of physiological disorders in 'Scifresh' apples. The overhead sprinkler irrigation system was activated when the air temperature reached 27 °C, with constant pulses maintained to ensure that the air temperature never exceeded the critical values of 29 °C for three months prior to harvest. The treatments were: (1) control without evaporative cooling; (2) microsprinkler irrigation with 0.6 L/h discharge rate; (3) sprinkler irrigation with 2 L/h discharge rate. The results indicated that overhead sprinkler irrigation reduced sunburn incidence by up to 90% as well as its severity, although there was no significant improvement in fruit color. In postharvest, both irrigation systems decreased the incidence of bitter pit and lenticel breakdown, without affecting fruit ripening. However, fruit under sprinkler irrigation had a 10% increase in soft scald incidence.

Keywords: evaporative cooling; fruit color; heat stress; sunburn; *Malus domestica* Borkh.

1. Introduction

The apple 'Scifresh' is a bicolor cultivar derived from the cross between 'Braeburn' and 'Royal Gala', whose outstanding characteristics are texture and pleasant flavor. Initial trials indicated that it shows good adaptation to a variety of climates and areas such as in New Zealand, Washington (USA) and France (Volz et al., 2004). However, recent research has reported the incidence of sunburn, lack of color, bitter pit, and soft scald in warmer climates (Henriod et al., 2011).

High heating stress conditions during fruit growth affect fruit quality and condition, and this is particularly relevant especially in the current climate change scenario. Sunburn is one of the main problems for apple production in warm climates because it alters fruit appearance and composition (Racsko and Schrader, 2012). This alteration develops due to an excess of solar radiation on the fruit, which significantly increases its temperature (Schrader et al., 2001, 2003).

There are several cultural practices and technologies that have been developed to decrease sunburn incidence in fruit, such as: shade netting (Kalcsits et al., 2017), kaolin applications (Glenn et al., 2002; Wand et al., 2006) and the use of overhead sprinkler irrigation (Parchomchuk and Meheriuk, 1996), which affects the microclimatic conditions of the plant (Gindaba and Wand, 2005; Kalcsits et al., 2017). This protection systems should begin to operate when the air temperature exceeds 29 °C (Yuri et al., 2015).

Overhead sprinkler irrigation consists in spraying water on the plant in order to reduce heat stress. Evaporative cooling of the fruit is given by the energy needed to evaporate the water from its surface. This technique has shown to be effective in reducing fruit and canopy surface temperature in apple trees, especially in geographic areas with high temperatures and low relative humidity (Gindaba and Wand, 2005). The decrease in fruit temperature not only reduces sunburn incidence, but can also improve apple coloration (Iglesias et al., 2002, 2000). However, the effect of high irrigation on fruit quality and postharvest shell-life in 'Scifresh' apples has not been widely studied. This study aimed to evaluate the effect of overhead sprinkle irrigation on sunburn incidence, coloration, maturity parameters and development of physiological disorders in 'Scifresh' apples.

2. Materials and Methods

2.1. Plant material

The study was conducted in a commercial orchard located in San Clemente, Chile (35°31' S, 71°26' W) during the 2014/2015 growing season. 'Scifresh' apple trees (*Malus domestica* Borkh.) were planted in 2010 on M.9 rootstock with a spacing of 3.5 m × 1.2 m. Trees were trained as central axis, formed as a modified Solaxe. Orchard management was carried out according to commercial standards in the region.

2.2. Treatments

The treatments evaluated were: (1) control, without evaporative cooling; (2) overhead microsprinkler irrigation, with 0.6 L/h discharge rate; (3) overhead sprinkler irrigation, with 2 L/h discharge rate (Figure 1). The trial used a block design, each 5,000 m^2 (1,190 trees). Five trees per block were randomly selected for evaluation from the central rows.

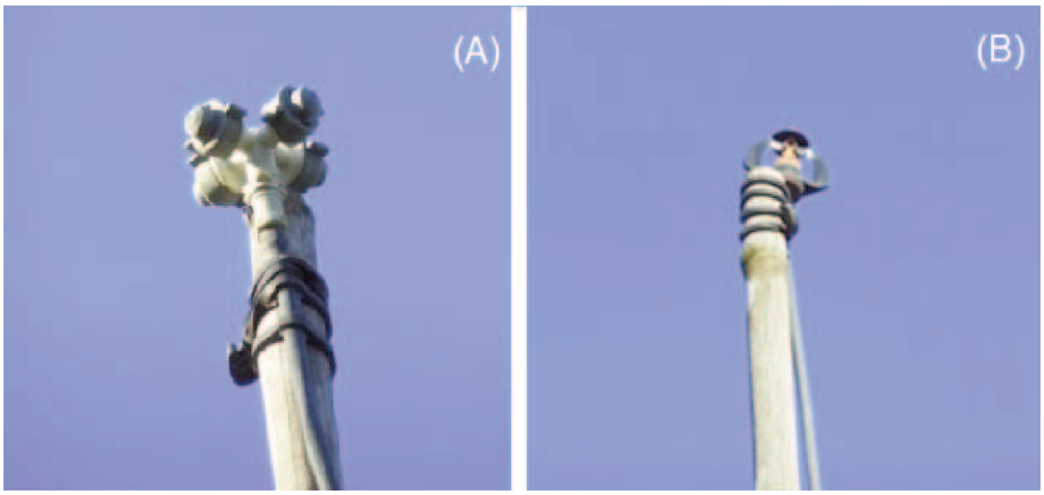

Figure 1. Overhead microsprinkler (**A**) and sprinkler (**B**) irrigation systems.

Both overhead irrigation systems were installed over the apple trees at 3.5 m height and with 2.4 m distance from each other. The overhead irrigation system was activated when the air temperature reached 27 °C, with constant pulses being maintained to ensure that air temperature never exceeded the critical values of 29 °C from December 2014 until harvest (carried out on 16 March 2015).

2.3. Climatic conditions

The location is characterized by a Mediterranean climate, with rainfall concentrated in winter, between May and August, while summers are hot and dry. Daily maximum and minimum temperatures are shown in Figure 2, where days with predisposing conditions for sunburn development (5 h T > 29 °C) were highlighted in red, according to the method proposed by Yuri (2015).

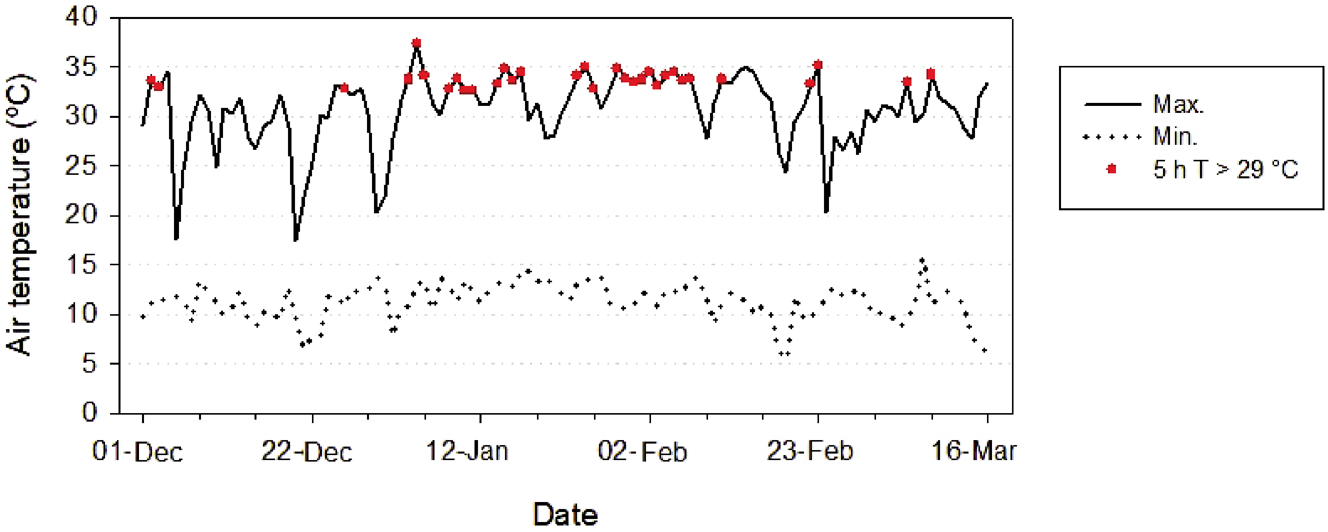

Figure 2. Daily maximum and minimum temperatures, red dots indicate days with conditions for sunburn development in apples (5 h T > 29 °C), from December 1, 2014, to March 16, 2015.

2.4. Fruit quality and condition

Fruit of the three treatments were picked at commercial harvest date. Fruit color, sunburn and russet were evaluated on five trees per treatment, harvesting all fruit, and expressed as percentages. Skin color was classified by three categories: (1) > 40% red; (2) 30–40% red and (3) < 30% red. Sunburn and russet incidence (%) were determined visually according to three injury categories: (1) healthy; (2) mild; (3) and moderate-severe.

Fruit maturity indices at harvest were measured in a random sample of 20 fruits per treatment. Flesh firmness (N) was determined using a Fruit Texture Analyzer GS14 (Güss, Strand, South Africa) equipped with an 11 mm probe, taking two readings per fruit, after the skin removed. Soluble solids concentration (SSC; °Brix) was determined using a portable thermo-compensated refractometer ATC 1 (Atago, Tokyo, Japan). Starch index was evaluated using the starch iodine staining test and visually evaluated using the starch scale from 1 to 10 developed by the Centre Technique Interprofessionnel des Fruits et Légumes (CTIFL; France).

Additionally, a sample of 100 fruits per treatment were stored under commercial postharvest conditions (0.0 ± 0.5 °C; 85–90% RH) for 90 days and then exposed to room temperature (20 °C; 50–60% RH) for 10 days to simulate shelf-life and evaluate maturity quality in both moments. Moreover after 10 days of shelf-life, the occurrence of physiological disorders such as bitter pit, lenticel blotch pit, lenticel breakdown, and soft scald, and fruit rots were evaluated in 100-fruit samples. Results were expressed as percentage of fruit with injuries.

2.5. Statistical analysis

Analysis of variance (ANOVA) was conducted to determine the significance of the differences between treatments in all the measured parameters. Tukey test (with p = 0.05) was used for mean separation. Statistical analysis was performed using Statgraphics Centurion XVI software (Warrenton, Virginia, USA). Figures were generated using SigmaPlot 10 software (WPcubed GmbH, München, Germany).

3. Results

Sunburn reached a total incidence of 19% of the total fruit in the control treatment, with about 40% of the fruit having mild sunburns and the rest (around 60% of the fruits) having moderate-severe symptoms (Figure 3). In treatments with overhead irrigation, sunburn decreased significantly, reaching only

2% and 6% injured fruits with microsprinkler and sprinkler treatments, respectively. Fruit subjected to overhead irrigation systems showed almost no moderate-severe injuries (Figure 3). In all treatments the incidence of russet was negligible (less than 2% of the fruits).

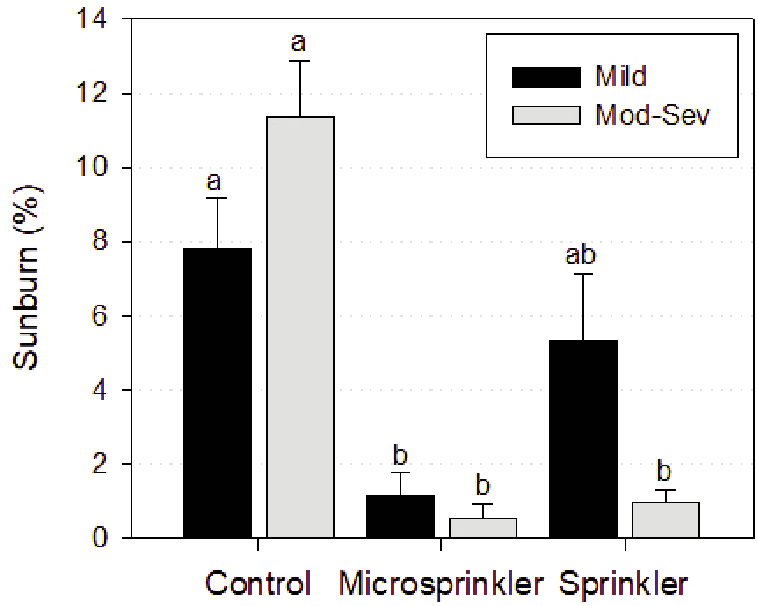

Figure 3. Effect of overhead sprinkler irrigation treatments on sunburn incidence (mild and moderate-severe categories) of 'Scifresh' apples at harvest. Each value corresponds to the percentage of sunburned fruit from an average of five trees and 124 fruit per tree. Different letters indicate significant differences between treatments according to the Tukey test ($p < 0.05$).

Regarding fruit skin coloration, in the sprinkler irrigation treatment 81% of fruits were classified as > 40% red, whereas in the microsprinkler treatment this incidence was 60%, the latter did not significantly differ from the control. In the microsprinkler treatment, 34% of the fruits fell in the category < 30% red, corresponding to a two-fold increase compared to the other treatments (Figure 4).

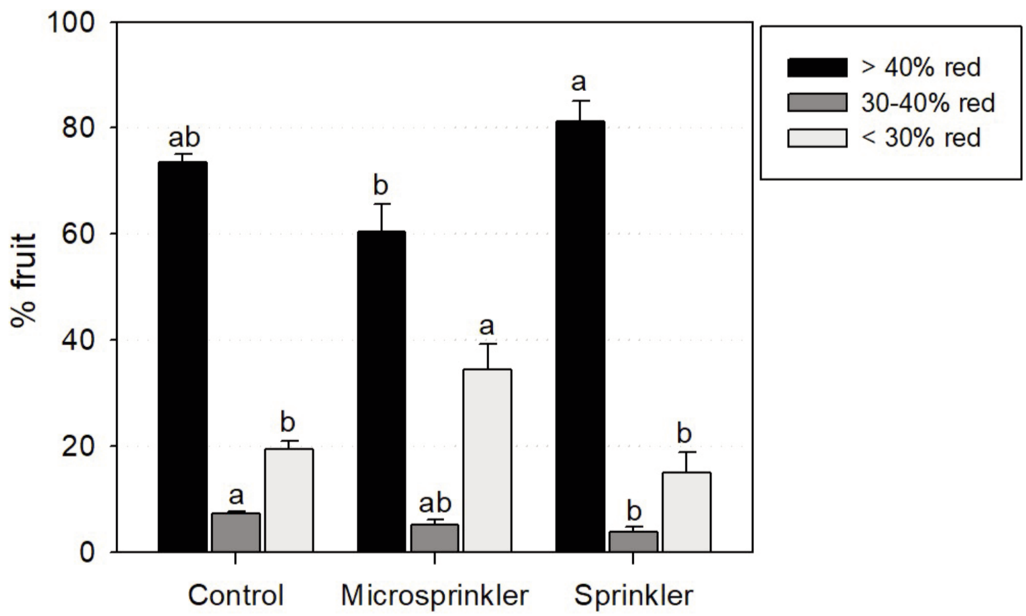

Figure 4. Effect of overhead sprinkler irrigation treatments on skin color in 'Scifresh' apples at harvest. Each value corresponds to the percentage of fruit according to color category of an average of five trees and 124 fruit per tree. Different letters indicate significant differences between treatments according to the Tukey test ($p < 0.05$).

At harvest, flesh firmness and SSC of fruits from both treatments with overhead irrigation were lower compared to fruits from the control trees, whereas no significant differences were observed between treatments in starch degradation (Table 1).

Table 1. Fruit maturity indices of 'Scifresh' apples assessed at harvest, cold storage (90 days at 0 °C) and cold storage + shelf life (90 + 10 days at 20 °C).

Sampling time	Treatments	Flesh firmness (N)	SSC (°Brix)	Starch index (1–10)[x]
Harvest	Control	83 a	16.5 a	9.4 a
	Microsprinkler	77 b	14.3 b	7.5 a
	Sprinkler	75 b	13.7 b	9.5 a
	p-value	*0.03*	*0.01*	*0.06*
Cold storage	Control	71 a	15.1 a	10.0 a
	Microsprinkler	73 a	15.7 a	10.0 a
	Sprinkler	70 a	13.8 b	10.0 a
	p-value	*0.36*	*0.03*	*1.00*
Cold storage + shelf-life	Control	74 a	16.0 a	10.0 a
	Microsprinkler	68 a	14.3 a	10.0 a
	Sprinkler	69 a	14.8 a	10.0 a
	p-value	*0.19*	*0.08*	*1.00*

Mean values within a column with different letters are significantly different (Tukey test at $p \leq 0.05$), n = 20 fruit per treatment per sampling time. [x]Starch index: 1 = no starch degradation, 10 = total starch degraded. SSC: Soluble solids concentration.

After 90 days of cold storage, the differences in maturity among treatments were not significant, except for SSC, which was lower in fruit from the sprinkler treatment. At the end of the shelf-life experiment (90 days cold storage + 10 days at 20 °C), there were no differences among treatments, with flesh firmness remaining above 68 N in all cases (Table 1).

Fruit from trees under overhead sprinkler irrigation showed a lower incidence of bitter pit and lenticel breakdown than the control (Table 2). Less than 2% incidence of lenticel blotch pit and fruit rot was observed among treatments; however, soft scald was increased by sprinkler irrigation reaching an incidence of 11%.

Table 2. Physiological disorders and decay in 'Scifresh' apples at cold storage + shelf life (90 + 10 days at 20 °C).

Treatments	Physiological disorders (%)				Decay (%)
	Bitter pit	Lenticel blotch pit	Lenticel breakdown	Soft scald	
Control	22.0 a	0.9 a	10.0 a	1.7 b	1.7 a
Microsprinkler	6.1 b	0.0 a	2.6 b	2.6 b	0.0 a
Sprinkler	0.9 b	0.9 a	0.0 b	11.0 a	0.0 a
p-value	*0.00*	*0.62*	*0.00*	*0.00*	*0.40*

Mean values within a column with different letters are significantly different (Tukey test at $p \leq 0.05$), n = 100 fruit per treatment.

4. Discussion

The increase in air temperature is a predisposing factor for sunburn and reduced development of red color in apples (Saure, 1990; Schrader et al., 2001; Schrader et al., 2003). The weather conditions measured at the experimental site were highly predisposing fruit sunburn development, as 32 days with temperatures above 29 °C for more than 5 h (Figure 1). The evaporative cooling systems with overhead irrigation were highly effective in reducing sunburn incidence, especially the most severe symptom category (Figure 2).

The water consumption of each sprinkler system is a relevant factor to consider to sunburn control efficiency. The sprinkler system provided greater water coverage over the canopy (0.7 L s^{-1} ha^{-1}) than the microsprinkler system (0.2 L s^{-1} ha^{-1}). Evans et al. (1995) indicated that higher water application rates (≥ 6 L s^{-1} ha^{-1}) would be more effective than lower ones in reducing fruit temperature by evaporative cooling. However, in terms of sunburn incidence reduction, our study did not show significant differences between the two systems and even less for the russet incidence. Previous studies on apples showed greater effectiveness of the overhead sprinkler irrigation system in preventing the occurrence of severe fruit sunburn injuries (Parchomchuk and Meheriuk, 1996; Reig et al., 2020). Despite this, Gindaba and Wand, (2005) pointed out that under high solar radiation conditions, systems only reducing fruit temperature would not be sufficient to prevent this alteration. In Chile, overhead sprinkler irrigation and shade netting have been proven to be the most efficient ways to control sunburn, whereas kaolin reflective particle film was the only chemical product showing some effectiveness (Yuri, 2015).

The export of 'Scifresh' apples as Jazz™ category requires over 40% fruit skin red coloration. In our study, the systems with overhead sprinkler irrigation induced an average of 71% of the fruit in this category, with no significant differences with the control (Figure 3). The microsprinkler irrigation system induced 34% of the fruit in the discard category (< 30% red) versus an average of 17% obtained in the Sprinkler and Control treatments. Cool nights promote the development of red pigments in apples (Saure, 1990). Studies in 'Jonagold' apples showed that overhead sprinkler irrigation had no effect on fruit coloration (Parchomchuk and Meheriuk, 1996). However, studies in Spain, where daily minimum temperatures were above 15 °C in preharvest, the use of irrigation 30 days before harvest date showed a significant increase in the coloration of 'Troped Delicious' and 'Mondial Gala' apples (Iglesias et al., 2005, 2002). Similar results were reported for 'Honeycrisp' apples (Willsea et al., 2023). In Chile, a standard practice to enhance apple color is the use of reflective mulch, especially when used in combination with shade-nets conditions (Yuri et al., 2024).

Flesh firmness and SSC in fruit under overhead sprinkler irrigation were significantly lower values than in fruit control, although these differences decreased after storage (Table 1). In 'Jonagold' apples, a reduction of SSC was reported using microsprinkler irrigation, without effect on flesh firmness and fruit coloration (Parchomchuk and Meheriuk, 1996), while in 'Troped Delicious' and 'Mondial Gala' apples, an increase in flesh firmness and SSC was reported with microsprinkler and sprinkler irrigation (Iglesias et al., 2005, 2002). However, external factors such as fruit load could affect fruit maturity to a greater extent than treatments to mitigate stress (Serra et al., 2016; Yuri et al., 2019).

The main physiological disorders affecting 'Scifresh' apples during cold storage are bitter pit, lenticel breakdown, and soft scald (Henriod et al., 2011). In the present study, the incidence of bitter pit and lenticel breakdown was lower in fruits treated with overhead irrigation than in control fruits. This effect was particularly evident in the Sprinkler treatments (the incidence of both disorders was lower than 1%; Table 2). Pre-harvest factors influencing the occurrence of bitter pit are those that limit calcium supply to the fruit, either due to excessive vegetative vigor, low fruit load, water stress, or high temperatures (daytime and nighttime temperature above °C and 10 °C, respectively) and low relative humidity (Curry, 2003; Moggia et al., 2006; Van Der Boon, 1980). Likewise, these factors promote lenticel breakdown due to their effect on increasing fruit growth rate without cuticle development (Turketti et al., 2012). Although leaf transpiration is reduced while water is applied (Green et al., 2014), net CO_2 assimilation rate was increased by the evaporative cooling system (Gindaba and Wand, 2007).

The incidence of soft scald was mainly observed in fruits of the Sprinkler treatment (Table 2). The mechanism of soft scald development in apples is still unclear, being particularly studied in 'Honeycrisp' apples, given their high susceptibility to soft scald (Lachapelle et al., 2013; Leisso et al., 2019; Al Shoffe et al., 2020). The factors that can increase its susceptibility are humidity conditions, preharvest rain, and cold temperatures during fruit development (Lachapelle et al., 2013: Moran et al., 2009), late harvests (Tong et al., 2003), and improper storage temperature management (Watkins et al., 2004). In our study, the incidence of soft scald was inversely related to bitter pit incidence, as reported by Amogi et al. (2025), and Tong et al. (2003).

Additional considerations should be done before the implementation and operation of overhead sprinkler irrigation on apple trees. In Chile, this system can cost between US$ 5,000–6,000/ha (Yuri et al., 2017). Therefore, it is not recommended for sunburn incidences of less than 10%, depending on productivity per hectare and fruit sales price. The profitability of the system can be increased by using it not only to reduce sunburn but also to improve fruit color and control frost damage (Iglesias et al., 2005). Another critical factor to consider when using overhead sprinkler irrigation during fruit development is water quality, which can affect fruit appearance due to salt accumulation on their surface. This was evidenced during our trial (Figure 5). Yuri et al. (2000) reported an increase in calcium and magnesium carbonates in fruit under overhead sprinkler irrigation, which are difficult to remove during packinghouse processing. Therefore, water purity must be taken into consideration and thus the use of water from deep wells is recommended. In addition, a high water input can have negative impacts, such as soil waterlogging and weed proliferation.

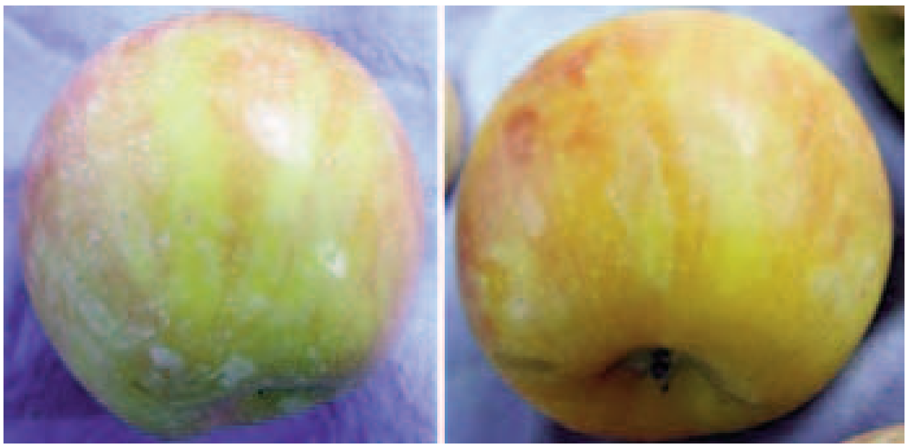

Figure 5. Salt residue on surface of 'Scifresh' apples under microsprinkler (left) and sprinkler (right) overhead irrigation.

5. Conclusions

The results obtained for a 'Scifresh' apple orchard showed that, in a season characterized by high preharvest heat stress, overhead irrigation by microsprinkler reduced sunburn incidence and severity, while the Sprinkler also improved fruit coloration. In postharvest, the apples under both overhead irrigation systems showed a lower incidence of bitter pit and lenticel breakdown, while soft scald increased by almost 10% in the sprinkler treatment. The greater incidence of soft scald obtained in trees under overhead sprinkler irrigation, in addition to a greater use of water in the orchard, show that its implementation to reduce sunburn and improve color is not justified under the conditions evaluated, and that in cases of lower color development it is preferable to use overhead irrigation systems with a lower flow rate, complemented with reflective mulch along the rows.

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Conflicts of Interest: The authors declare no conflict of interest.

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