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Evaluation of 'Sun Protect' in protecting apples (*Malus* × *domestica* Borkh.) against sunburn

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Abstract

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Sunburn is a major type of solar radiation injury that leads to significant economic losses in several fruits, including apples. Here, the efficiency of a new product, called 'Sun Protect', in protecting apples (cv. Granny Smith) against sunburn was tested. The effect of 'Sun Protect' application was further examined on fruit quality characteristics, including soluble solids, acidity, flesh firmness, total phenol content and antioxidant activity, at harvest and after a 4-month period of storage. Spraying apple trees with 'Sun Protect' resulted in better fruit coloration and no visual symptoms of sunburn. On the other hand, fruit quality characteristics were not affected by the treatment. After storage for four months, apples sprayed with 'Sun Protect' retained their intense green colour in relation to the green-yellowish appearance of the untreated ones. Results on photosynthetic parameters revealed that there was no negative effect of the treatments on gas exchange of the leaves; moreover, sprayed trees showed a higher water use efficiency in comparison to the control. Our results provide evidence that 'Sun Protect' protects apples from sunburn injury and increases their marketability.

Keywords: antioxidant activity; firmness; fruit colour; photosynthesis; sunburn

Apple (*Malus* × *domestica* Borkh.) is one of the most important fruit crops cultivated worldwide. Among fruit quality characteristics, apple peel colour is an important factor that determines apple marketability and anything that adversely affects the appearance reduces the market value of the fruit. As such, apple sunburn, a fruit discoloration caused by intensive solar radiation and heat, greatly reduces the price of affected fruits (Schrader et al. 2003; Felicetti, Schrader 2009). It is estimated that losses in apple production due to sunburn in Washington State (USA) average about 10% if no protective measures are taken (WSU Tree fruit research and extension centre, http://hort.tfrec.wsu.edu/finish.php). In Aus-

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tralia, losses can reach 40–50%, especially for sensitive apple cultivars (Lolicato 2011).

The apple cv. Granny Smith, which is mainly cultivated in lowland areas in Greece, is sensitive to sunburn (Lolicato 2011). The damage on the fruit peel appears either as a discoloration (yellowish), or in more severe cases as a brown necrotic spot, leading eventually to a complete loss of the commercial value of the fruit and decreased storability.

The types of sunburn are the following: (i) Sunburn necrosis. This appears as a sunken dark brown or necrotic patch on the side of fruit exposed to the sun. It is usually caused by heat generated in fruit by direct sunlight, when the fruit surface temperature of an apple reaches 52 ± 1°C for 10 min., (ii) Sunburn browning. This appears as a yellow or brown patch on the side of the apple exposed to the sun. Cells do not die and damage initially appears superficial, although deeper layers may show more damage after cool storage. Sunburn browning in apples normally begins to appear when fruit surface temperatures rises up to 46 to 49°C for one hour, depending on different cultivars, (iii) Photo-oxidative sunburn. This initially appears as white, bleached skin in a patch on the side of apples exposed to the sun, that later becomes brown and sometimes also necrotic. It can occur at relatively low air temperature and already at a surface temperature of less than 45°C (Fellicetti, Schrader 2008).

Various measures can be taken in order to protect apples against sunburn. These may include the use of shade nettings, over-tree sprinkler cooling systems and spray-on products (Glenn 2009; Evans, Lolicato 2011; van der Gulik 2011).

The scope of this research was to test the efficacy of the spray-on product 'Sun Protect' in protecting the apple fruit from sunburn. We further examined whether 'Sun Protect' affects the quality characteristics of the fruit. The apple cv. Granny Smith was selected for this study, due to its high sensitivity to sunburn.

MATERIAL AND METHODS

Plant material, growth conditions and data collection. Mature trees of the apple cv. Granny Smith grafted onto M9 rootstock were chosen for the study. The trees were 12 years old, planted in a randomized complete block design with 3.5 × 4 m spacing and trained to a palmette system. 25 trees were used for each treatment (five replications × five trees). The orchard was managed with standard horticultural practices regarding irrigation, pruning, and fertilization.

Apple trees were sprayed with 1 l/ha 'Sun Protect' (Compo-Expert GmbH, Münster, Germany) for two successive years (2013 and 2014) in an apple orchard located in northern Greece on the following dates: June 19, June 26, August 2, August 9 and August 16. Control trees were not sprayed. Table 1 shows the meteorological data during apple fruit development and maturation for the growing seasons 2013 and 2014.

Forty apples were collected from each treatment at the stage of their commercial maturity. Fruits were transported immediately to the laboratory for analyses. Fruits were weighted and evaluated for colour, soluble solids, acidity, and flesh firmness, as previously described by Koukourikou-Petridou et al. (2007). In addition, total phenol content (Singleton et al. 1999) and antioxidant activity (Benzie, Strain 1996) were determined. Finally, fruits from the untreated control and from the treated trees were placed into a common cooling chamber

Table 1. Meteorological data during apple fruit development and maturation for the growing seasons 2013 and 2014

	Mean temperature (°C)		Max. temperature (°C)		Mean radiation (W/m^2)		Max. radiation (W/m^2)		Rainfall (mm)	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
June	22.80	22.7	33.80	35.1	272.90	279.70	1,137.0	1,084.0	199	47
July	25.30	24.6	35.20	33.7	290.80	279.90	1,060.0	1,165.0	28	133
August	26.50	25.4	35.20	34.4	266.80	262.30	948.0	999.0	4	16
September	21.10	19.1	28.90	26.4	209.70	165.10	932.0	1,018.0	25	134
Mean	23.93	22.95	33.28	32.4	260.05	246.75	1,019.3	1,066.5	–	–
Total	–	–	–	–	–	–	–	–	176	330

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Table 2. Classification of apple fruits (cv. Granny Smith) based on the colour and sunburn injury during harvest

Year	Treatment	Class I (> 90% green)	Class II (< 90% green)	Class III (sunburn)
2013	'Sun Protect'	69[a]	31[b]	0[b]
	Control	16[b]	72[a]	12[a]
2014	'Sun Protect'	84[a]	16[b]	0[a]
	Control	27[b]	73[a]	0[a]

means in the same column for each year followed by different letters are significantly different (Fischer's *F*-test, $P \leq 0.05$)

for a period of 4 months. For these fruits, the same quality parameters were determined.

Photosynthetic parameters such as photosynthetic rate, transpiration and stomatal conductance were measured with the LCi portable gas exchange system (ADC BioScientific Ltd., Herts, UK) from 11.00 am till 13.00 pm at harvest (mid-September). Instantaneous water use efficiency was estimated as the ratio of photosynthetic rate to transpiration rate.

Statistical analysis. All parameters were compared separately for each year and data were subjected to one-way ANOVA using the SPSS 17.0 for Windows statistical package (SPSS, Chicago, USA). Comparison among the means to determine statistical differences was performed using Fischer's *F*-test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Granny Smith cv. apple fruits were classified into three commercial categories regarding their colour: Class I (> 90% green surface), class II (< 90% green surface), and class III (visual spots, including sunburn).

To examine whether the application of 'Sun Protect' on apple trees leads to better fruit coloration in comparison to untreated ones, the colour of apples was scored (Table 2). For both growing seasons, application with 'Sun Protect' resulted in a higher percentage of green fruits (class I), whereas less than 1/3 of apples were categorized as class II (Fig. 1). Moreover, no symptoms of sunburn were evident. By contrast, the majority of control fruits belonged to class II and only a small percentage to class I. Fruits displaying sunburn symptoms were also observed (12%) in the control, but only in 2013. 'Sun Protect' is a mixture of UV absorbing compounds, α-tocopherol, phenolic acids and boron. Whereas UV absorbing compounds and phenolic acids provide direct protection from solar radiation, α-tocopherol has a key role in protection against lipid peroxidation caused by high light stress (Havaux et al. 2003). α-tocopherol may also have additional protective effect by stabilizing membrane structure through interaction with polyunsaturated fatty acid

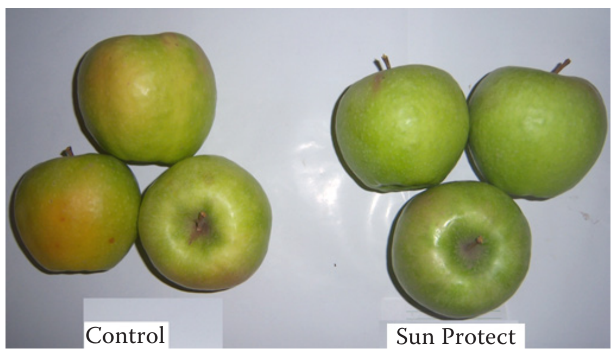

Fig. 1. Cv. Granny Smith fruit coloration at harvest

Table 3. Soluble solids, acidity, and firmness of apple fruits (cv. Granny Smith) during harvest

Year	Treatment	Soluble solids (°Brix)	Acidity (% malic acid)	Fruit firmness (kg/cm^2)
2013	'Sun Protect'	12.93[a]	0.85[a]	8.02[a]
	Control	13.70[a]	0.81[a]	8.11[a]
2014	'Sun Protect'	12.28[a]	0.81[b]	8.45[a]
	Control	12.20[a]	0.90[a]	7.85[a]

means in the same column for each year followed by different letters are significantly different (Fischer's F-test, $P \leq 0.05$)

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Table 4. Total phenol content (TPC) and antioxidant activity of apple fruits (cv. Granny Smith) during harvest

Year	Treatment	TPC (mg GAE/g FW)	Antioxidant activity (μmol AAE/g FW)
2013	'Sun Protect'	1.76[b]	9.16[b]
	Control	2.22[a]	11.76[a]
2014	'Sun Protect'	2.12[a]	9.75[a]
	Control	2.22[a]	10.95[a]

means in the same column for each year followed by different letters are significantly different (Fischer's F-test, $P \leq 0.05$); AAE – ascorbic acid equivalents, GAE – gallic acid equivalents

Fig. 2. Coloration of cv. Granny Smith fruits after 4 months in storage

(Sattler et al. 2003). According to the visual observation of apple fruits, these photo-protective compounds provide an efficient shield against sunburn and result in better fruit coloration.

To clarify whether application of 'Sun Protect' affects fruit quality characteristics, we determined soluble solids, acidity, flesh firmness, total phenol content (TPC), and antioxidant activity measurements. Soluble solids and fruit firmness were the same in comparison of treated and control trees (Table 3). Fruit acidity was higher in control compared to treated apples, but only in 2014 (Table 3). TPC and antioxidant activity were higher in the control fruits in 2013, but there was no difference between treatments in 2014 (Table 4).

We further examined fruit quality characteristics on apples stored for four months in cooling chambers. Apples treated with 'Sun Protect' retained their intense green colour, whereas control fruits developed a green-yellowish coloration (Fig. 2). In 2013, acidity and fruit firmness were higher in 'Sun Protect'-treated fruits, whereas soluble solids content was lower (Table 5). In 2014, there was no difference in soluble solids content and flesh firmness between treatments, whereas acidity was higher in the fruits treated with 'Sun Protect'.

Total phenol content and antioxidant activity of apple fruits after a four-month period of storage did not differ significantly in both years (Table 6).

After a four-month period of storage in 2013, lightness (L) of fruits was significantly higher in the 'Sun Protect' treatment compared to the control, whereas there was no difference in 2014 (Table 7). Fruits were greener (i.e. higher negative a values) in the 'Sun Protect' treatment in both years.

In 2013, photosynthetic rate of leaves did not differ among treatments, transpiration was higher in the control treatment than the 'Sun Protect' treat-

Table 5. Soluble solids, acidity, and firmness of apple fruits (cv. Granny Smith) after a four-month period of storage

Year	Treatment	Soluble solids (°Brix)	Acidity (% malic acid)	Fruit firmness (kg/cm^2)
2013	'Sun Protect'	14.63[b]	0.67[a]	6.94[a]
	Control	15.82[a]	0.54[b]	6.35[b]
2014	'Sun Protect'	13.58[a]	0.64[a]	5.26[a]
	Control	13.45[a]	0.54[b]	4.90[a]

means in the same column for each year followed by different letters are significantly different (Fischer's F-test, $P \leq 0.05$)

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Table 6. Total phenol content (TPC) and antioxidant activity of apple fruits (cv. Granny Smith) after a four-month period of storage

Year	Treatment	TPC (mg GAE/g FW)	Antioxidant activity (µmol AAE/g FW)
2013	'Sun Protect'	2.32[a]	9.00[a]
	Control	2.48[a]	9.10[a]
2014	'Sun Protect'	2.64[a]	12.90[a]
	Control	2.46[a]	12.90[a]

means in the same column for each year followed by different letters are significantly different (Fischer's F-test, $P \leq 0.05$); AAE – ascorbic acid equivalents; GAE – gallic acid equivalents

Table 7. Colour measurements (L (lightness), a (range from red to green) and b (range from yellow to blue)) of apple fruits (cv. Granny Smith) after a four-month period of storage

Year	Treatment	L	a	b
2013	'Sun Protect'	71.19[a]	–15.99[a]	41.89[a]
	Control	65.12[b]	–11.24[b]	42.38[a]
2014	'Sun Protect'	71.91[a]	–14.71[a]	44.14[a]
	Control	72.87[a]	–10.86[b]	47.21[a]

means in the same column for each year followed by different letters are significantly different (Fischer's F-test, $P \leq 0.05$)

Table 8. Photosynthetic rate, transpiration, water use efficiency and stomatal conductance of leaves at harvest period in 2013 and 2014

Year	Treatment	Photosynthetic rate (µmol CO_2/m^2·s)	Transpiration (mmol H_2O/m^2·s)	Water use efficiency (µmol CO_2/mmol H_2O)	Stomatal conductance (mol H_2O/m^2·s)
2013	'SunProtect'	21.73[a]	4.97[b]	4.52[a]	0.67[a]
	Control	19.79[a]	6.43[a]	3.08[b]	0.50[b]
2014	'SunProtect'	14.99[a]	3.85[a]	3.89[a]	0.38[a]
	Control	9.60[b]	4.90[a]	1.96[b]	0.22[b]

means in the same column for each year followed by different letters are significantly different (Fischer's F-test, $P \leq 0.05$)

ment, whereas instantaneous water use efficiency and stomatal conductance were higher in the 'Sun Protect' treatment compared to the control (Table 8). In 2014, photosynthetic rate of leaves, water use efficiency and stomatal conductance were higher in the 'Sun Protect' treatment compared to the control, whereas transpiration rate did not differ among treatments (Table 8). Results on photosynthetic parameters revealed that there was no significant negative effect of the treatments on gas exchange of the leaves. Especially in 2014, photosynthetic activity was enhanced by 'Sun Protect' while instantaneous water use efficiency was improved in both years in the treated trees.

Apple fruit colour is a dominant factor for consumer acceptance and a main determinant of the market value. In general, fruits belonging to 'class I' (intense green colour) will receive higher prices in the market and therefore it is a major goal for the growers to produce fruits of premium classification. Since application of 'Sun Protect' on apple trees resulted in higher percentage of premium class fruits, it is conceivable that the gross income of the growers will be positively affected.

In conclusion, application of 'Sun Protect' on apple trees protected fruit effectively from sunburn injury and resulted in better fruit coloration. Although other fruit quality parameters were not sig-

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nificantly affected, it is obvious that apple growers will take advantage from the use of 'Sun Protect'.

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