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ARTICLE

Postharvest quality implications of preharvest treatments applied to enhance Ambrosia™ apple red blush colour at harvest

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Abstract: Two approaches for enhancing red blush in Ambrosia™ apple were evaluated: (*i*) reflective row covers or (*ii*) application of foliar phosphorus-rich sprays, both applied several weeks before anticipated harvest. Two experiments were conducted, the first to evaluate a white reflective row cover versus foliar phosphorus spray, and the second to evaluate two types of reflective row cover, one made of a woven white polyethylene sheet and the other a solid silvered Mylar®. The comparative effects of these preharvest treatments on at-harvest fruit quality and quality after storage were assessed in both experiments. It was determined that foliar phosphorus sprays or one of the two types of reflective row covers resulted in similar enhancement of red blush colour, with no negative effects on at-harvest quality. However, in the first experiment it was found that after 8 mo of controlled-atmosphere storage (1 kPa O_2 + 1 kPa CO_2 at 0.5 °C), apples from the phosphorus foliar spray treatment developed greasiness and sooty blotch compared with those from the reflective row cover or control treatments. In the second experiment, after 5 mo of air storage at 0.5 °C, the apples from the silvered Mylar® reflective row cover treatment developed severe soft scald and soggy breakdown compared with the control and white reflective row cover treatments, which developed lower or very slight incidence of soft scald, respectively, and no soggy breakdown. These results indicate that when preharvest treatments are applied to apples, post-storage quality effects should be evaluated.

Key words: Soft scald, soggy breakdown, sooty blotch, greasiness, reflective row covers, foliar phosphorus sprays.

Résumé : Les auteurs ont évalué deux approches visant à intensifier la coloration rouge des pommes Ambrosia[MC] ; (*i*) l'usage de minitunnels réfléchissants et (*ii*) la pulvérisation sur les feuilles d'un produit riche en phosphore plusieurs semaines avant la cueillette. À cette fin, ils ont réalisé deux expériences, la première pour comparer l'usage d'un minitunnel réfléchissant blanc à la pulvérisation foliaire de phosphore, et la seconde pour évaluer deux types de minitunnels réfléchissants, le premier en polyéthylène blanc tissé, l'autre en Mylar® argent uni. Dans les deux cas, les auteurs ont comparé l'effet des traitements précédant la cueillette sur la qualité des fruits à la récolte et après leur entreposage. La pulvérisation foliaire de phosphore et un des deux minitunnels réfléchissants ont amélioré de façon similaire la teinte rouge des fruits, sans que leur qualité à la récolte en souffre. Cependant, au terme de la première expérience, on s'est rendu compte qu'après huit mois d'entreposage sous atmosphère contrôlée (1 kPa O_2 + 1 kPa CO_2 à 0,5 °C), les pommes des arbres dont les feuilles avaient été pulvérisées avec du phosphore avaient pris un aspect graisseux et développé la tache de suie, ce qui n'était pas le cas pour celles venant des pommiers protégés par un minitunnel réfléchissant ou des pommiers témoins. Dans la deuxième expérience, après avoir entreposées à l'air à 0,5 °C pendant cinq mois, les pommes des arbres protégés avec le minitunnel en Mylar® argent avaient développé une forme grave d'échaudure molle et de vitrescence, comparativement à celles récoltées sur les arbres témoins ou ceux protégés par le minitunnel blanc, qui présentaient respectivement moins d'échaudure molle et aucune vitrescence. Ces résultats indiquent que lorsqu'on traite les pommiers avant la récolte, on devrait aussi évaluer les effets de l'entreposage sur la qualité des fruits. [Traduit par la Rédaction]

Mots-clés : échaudure molle, vitrescence, tache de suie, aspect graisseux, minitunnels réfléchissants, application foliaire de phosphore.

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Introduction

Ambrosia™ apple is a relatively new apple cultivar and is enjoying a rapid gain in popularity (Cline et al. 2008). An important component of Ambrosia™ value in the market is the degree of blush colour and coverage on the fruit (Cline et al. 2008). This requirement poses a challenge to some orchards, as colour development can lag behind apple fruit maturation on the tree (Schmidt et al. 2010).

There are several possible products available commercially that have putative benefits in enhancing or accelerating blush colouration, of which there are two general approaches: (*i*) application of a reflective row cover to enhance colour development (Mathieu and D'Aure 2000; Schmidt et al. 2010), or (*ii*) foliar sprays with fertilizers containing phosphorus (Larrigaudiere et al. 1996; Paliyath et al. 2002). Whereas these published studies demonstrated the at-harvest quality of apples in response to different types of reflective row covers or foliar sprays to enhance red blush, there have not been any studies published to evaluate the comparative effect of these approaches and materials on the post-storage quality of treated apples. Therefore, this work was conducted in the first year to evaluate and compare the postharvest quality of Ambrosia apples after preharvest application of a white woven polyethylene reflective row cover versus using a foliar-applied red blush enhancer and, in the second year, to compare the postharvest quality of Ambrosia apples after preharvest application of two types of reflective row cover (a white woven polyethylene cover versus a solid silvered Mylar® row cover).

Materials and Methods

Preharvest treatments

In the first year, three commercial Ambrosia™ apple orchards of close proximity to each other in Cawston, BC, were selected. The orchards were located at lat. 49.20° N and long. −119.75° E (Orchard 1), at lat. 49.14° N and long. −119.73° E (Orchard 2), and at lat. 49.18° N and long. −119.74° E (Orchard 3). Global positioning coordinates were obtained from Google Maps (DigitalGlobe, Map Data, ©2018 Google Canada). They were physically located within a land area of 6.7 km × 2.1 km. At 4 wk prior to the estimated day of harvest (based on advice from BC Tree Fruits Company field services personnel), three treatments were established in each of the orchards: (1) Extenday™, a white woven polyethylene reflective row cover (woven cloth Extenday 82, formerly Extenday 6569); (2) Phosyn Hydrophos™ (Yara Canada Ltd, Montreal, QC), a foliar fertilizer containing 29% available phosphoric acid, 5% soluble potash, and 4% magnesium, which has previously been shown to improve red blush colour in apples (Paliyath et al. 2002); and (3) a control not having any treatment applied. The Extenday™ (Extenday New Zealand Ltd, Auckland, New Zealand) was laid over grass on both sides of the row being tested and tethered to tree bases with bungee cords to prevent lifting with the wind or with pedestrian or equipment traffic in the rows. Hydrophos™ concentrate was diluted to 0.2% in tap water (carried from the laboratory in carboys) and then applied using an 8 L backpack sprayer (Accu-Power 416, Solo Kleinmotoren GmbH, Sindelfingen, Germany). Two sprays were applied approximately four and two weeks before harvest (3 and 12 Sept. 2014). Control rows were selected several rows down from the Extenday™ and Hydrophos™ treatment blocks to mitigate the chance of light reflection or spray drift, respectively. Replicate blocks of trees were selected such that 15 trees in a row constituted a replicate and there were three spatially separated replicate blocks for each treatment at each of the three orchards. The orchardists were asked to continue with their normal irrigation and spray schedules until harvest.

In the second year, at 4 wk prior to the estimated day of harvest, three treatments were established at each orchard: (1) Extenday™, a white woven polyethylene reflective row cover; (2) Brite-N'up, a solid silvered Mylar reflective row cover (Peaceful Valley Farm Supply, Grass Valley, CA); and (3) a control not having any treatment applied. Both Extenday™ and Brite-N'up were secured to the trees in a similar fashion as described above for Extenday™ in the previous year of experimentation.

Field environment measures

The diurnal fluctuation of reflected photon flux density in the UVA and UVB range was measured from 11 to 21 Sept. (Julian days 254 to 264) using ultra violet sensors measuring total flux density between 250 and 400 nm (Model SU-100-SS, Apogee Instruments, Logan, UT). The sensors were positioned on an anchored post at a 2 m height in the tree canopy, oriented at a 45° downward angle towards the centre of the row. The sensors were shielded to ensure that the only UV light measured was that reflected from the row into the canopy for the control or the reflective row cover treatments. The analog output from these sensors was captured with a data logger (Model CR1000, Campbell Scientific, Edmonton, AB) and the data was subsequently downloaded into Excel.

A portable spectroradiometer (Licor Li-1800, Licor, Lincoln, NE) was set up in the orchards using metal tripod stands to allow measurement of reflected light quality/quantity differences from rows into the canopy for the control, white reflected row cover, and silvered Mylar® row cover treatments. The spectroradiometer was fitted with a quartz fiber optic probe to allow measurement of light reflected from the row into the canopy at a 1 m height. The sensor head was oriented at a 45° downward angle and shrouded to eliminate the potential of direct incident sunlight exposure. Data were transferred into Excel.

At-harvest measurements

For the first year of the experiment, apples were harvested on 23, 26, and 29 Sept. 2014 at orchards 1, 2 and 3, respectively, when the starch–iodine index had reached approximately 3.5–4 (Cline 2009). In the second year, apples were harvested when the starch–iodine index had reached approximately 2.9–3 (Cline 2009). The maturities of the individual fruit from each harvest were assessed with the starch–iodine index (Cline 2009), firmness measures, and the I_{AD} index value (Toivonen 2015) on 10 apples from each treatment, replicate, and orchard combination. The I_{AD} index was first determined on each apple with a difference in absorbance (DA) meter (Sinteleia, Bologna, Italy), taking precautions against artefacts (Toivonen et al. 2015), then the firmness was measured using a Fruit Texture Analyzer [Model GS-15, Güss Manufacturing (Pty) Ltd., Strand, South Africa] fitted with an 11.1 mm diameter probe. Finally, each apple was sliced in half equatorially and the top half of the apple sprayed to saturation with a solution of iodine–potassium iodide to determine the starch–iodine index (Smith et al. 1979). The lower half of each apple was juiced and the titratable acidity and soluble solids were determined. Soluble solids was determined from the juice with a digital refractometer (Refracto 30PX, Mettler Toledo, Mississauga, ON) and titratable acidity was determined with 15 mL of juice using an automated titrator (Model 719S, Titrino-Metrohm, Brinkmann, Mississauga) with 0.1 N NaOH to an end-point pH of 8.1. A Minolta CR-400/410 chromameter (Minolta, Ramsey, NJ) was used to quantitatively assess blush colour attributes on the CIE $L^*a^*b^*$ colour space. A blush colour index (BCI) (to quantify the intensity of the red colour) was calculated with an equation reported by Cliff et al. (2009):

$$\mathrm{BCI} = \frac{2000\,a}{\mathrm{L}\left(a^2 + b^2\right)^{\frac{1}{2}}}$$

where BCI is the blush colour index, L is the measured L^* value, a is the measured a^* value, and b is the measured b^* value. Blush coverage was assessed visually using the following scale: 0 = <5% of the apple surface, 1 = 5%–25% of the apple surface, 2 = 25%–50% of the apple surface, 3 = 50%–75% of the apple surface, and 4 = >75% of the apple surface. The background colour of the apple peel was calculated as hue angle (h°) using an SAS (SAS Institute Inc., Cary, NC) routine, which is described by McGuire (1992).

Storage protocols

Apples were placed into an 895 L volume, 6 mil polyethylene tent sealed onto a large sheet of vinyl flooring using duct tape in a 5 °C cold room, and 1-MCP treatment was applied as per the instructions provided by the company using research tablets and associated release solutions (AgroFresh, Spring House, PA). The apples were exposed to the treatment in the tent overnight (~14 h) and the tent was opened to ventilate the next morning. In 2014, the treated apples were then placed into six bushel capacity CA cabinets in a research CA system (Toivonen and Hampson 2014) consisting of small six bushel capacity aluminum storage chambers fitted with a circulating fan system (Storage Control Systems Inc., Sparta, MI). Atmospheres were checked each hour and were capable of maintaining O_2 and CO_2 within 0.2 kPa of target values using an ICA 61/CGS 610 CA Control System (International Controlled Atmosphere Ltd., Kent, UK), equipped with individual flow controllers for each storage chamber (Storage Control Systems Inc.). The storage chambers were placed in cold rooms set to 0.5 °C, and these were allowed to cool to room temperature for 1 d before sealing and initiating the CA regime. The target atmosphere of 1.0% O_2 with 1.0% CO_2 was achieved within 14 h after the cabinets were sealed and the atmosphere control program was initiated.

The apples were removed from these cabinets at 5 and 8 mo. In 2015, the treated apples were placed into a cold air storage room set to 0.5 °C and held there for 5 mo.

Post-storage measurements

In the first year of the experiment, apples were removed from controlled atmospheres after 5 and 8 mo and placed into a controlled environment cabinet set at 20 °C for 1 wk before analysis of post-storage quality. Greasiness was assessed by evaluating the relative slipperiness of the fruit when picked up with one hand. The scale used was 0 = no greasiness, 1 = slight greasiness, 2 = moderate greasiness, difficult to pick up, and 3 = severe greasiness, almost impossible to pick up. Sooty mould was assessed as 0 = none visible, 1 = slightly visible, 2 = moderate, covering a part of the apple, and 3 = severe, covering most of the apple. Apples were then washed to remove both the greasiness and sooty mould. The firmness was determined as described above using a Fruit Texture Analyser. Apples were then cut in half equatorially and the lower half was juiced to determine soluble solids and titratable acidity, as described above.

In the second year of the experiment, apples were removed from air storage at 0.5 °C after 5 mo and placed into a controlled environment cabinet set at 20 °C for 1 wk before analysis of post-storage quality. Defects were evaluated using visual and tactile rating scales. Neither greasiness nor sooty mold was detected in this experiment after 5 mo of air storage. However, soft scald and soggy breakdown were identified and their incidence within each replicate was quantified as a ratio between the number of affected fruit and the total number of fruit within the replicate ($n = 12$). The firmness was determined as described above using a Fruit Texture Analyser. Apples were then cut in half equatorially and the lower half was juiced to determine soluble solids and titratable acidity, as described above.

Experimental design and statistical analyses

In the first year (2014), the experimental design was 3 orchards × 3 row cover treatments × 2 storage durations. There were three replicates of each treatment combination and each replicate was composed of

Table 1. Analysis of variance to determine significance of influence of row cover treatments, orchard effects, and their interaction for at-harvest measures of I_{AD}, starch–iodine index, firmness, soluble solids blush colour index, and extent of peel coverage with red blush for an experiment conducted in the 2014 harvest season.

Source	I_{AD}[a]	Starch–iodine index	Firmness	Soluble solids content	Titratable acidity	Blush colour index	Extent of blush coverage
Row cover (RC)	<0.0001	0.1091	0.6722	0.0008	0.1255	<0.0001	<0.0001
Orchard (O)	<0.0001	0.0233	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
RC × O	0.2126	0.0535	0.7232	0.0248	0.1194	0.0016	<0.0001

[a]The I_{AD} is a relative measure of chlorophyll content in the apple peel and a decline of relative content is an indicator of Ambrosia™ apple maturity (Toivonen 2015).

Table 2. I_{AD} values at harvest for Ambrosia™ apples subjected to preharvest field treatments to enhance red blush colour formation in the peel.

Treatment	I_{AD} value at harvest[a]
Control	0.64 ± 0.02
White reflective row cover	0.54 ± 0.03
Foliar spray	0.64 ± 0.02

Note: The white reflective row cover (Extenday™) and foliar spray (Hydrophos™) treatments were applied 4 wk before the anticipated harvest date. Data are an average over three orchards. Means are an average of 75 fruit (25 from each of three orchards) ± standard error.

[a]The I_{AD} is a relative measure of chlorophyll content in the apple peel and a decline of relative content is an indicator of Ambrosia™ apple maturity (Toivonen 2015).

Table 3. Soluble solids content, red blush colour intensity (index), and relative red blush coverage for Ambrosia™ apples at harvest from three orchards in Cawston, BC, in 2014.

	Control	White reflective row cover	Foliar spray
Soluble solids (%)			
Orchard 1	11.0 ± 0.2	12.5 ± 0.1	12.3 ± 0.5
Orchard 2	11.0 ± 0.2	11.8 ± 0.1	10.6 ± 0.4
Orchard 3	9.2 ± 0.1	10.0 ± 0.2	10.3 ± 0.4
Blush colour index[a]			
Orchard 1	4.4 ± 1.0	36.6 ± 0.3	29.5 ± 2.6
Orchard 2	25.5 ± 1.3	40.7 ± 1.1	34.4 ± 1.0
Orchard 3	11.9 ± 4.3	41.2 ± 0.6	36.9 ± 2.7
Extent of blush coverage[b]			
Orchard 1	0.67 ± 0.07	3.83 ± 0.07	2.67 ± 0.24
Orchard 2	2.23 ± 0.19	3.97 ± 0.03	2.80 ± 0.10
Orchard 3	1.57 ± 0.12	3.57 ± 0.12	3.07 ± 0.09

Note: Apples were harvested from three preharvest field treatments, which included a non-treated control, two foliar preharvest sprays with Hydrophos™ at 4 and 2 wk before harvest, and the application of a white reflective row cover (Extenday™) 4 wk before harvest. Means are an average of three replicates ± standard error.

[a]Blush colour index was calculated from L^*, a^*, and b^* values collected using a Minolta Chroma meter using a method adapted from Cliff et al. (2009).

[b]0 = <5% of the apple surface, 1 = 5%–25% of the apple surface, 2 = 25%–50% of the apple surface, 3 = 50%–75% of the apple surface, and 4 = >75% of the apple surface.

15 apples. In the second year (2015), the experimental design was a simple factorial with 3 row cover treatments, each having four replicates. Each replicate was composed of 12 apples. Statistical analysis was performed using the general linear models procedure in SAS.

Results and Discussion

Experiment 1: reflective row cover versus foliar sprays to enhance red blush

The analysis of variance showed that there were differences between the three row cover treatments for I_{AD} index values, soluble solids content, blush colour index and extent of blush coverage at harvest (Table 1). Orchard effects were seen for all of the maturity or quality measures at harvest (Table 1). The only measures that showed interactions between row cover treatment and orchard were soluble solids content, blush colour index, and extent of blush coverage at harvest. The white reflective row cover treatment showed the most advanced maturity of the three treatments as measured by the I_{AD} value (Table 2), suggesting that this treatment accelerated maturation slightly compared with the control and foliar spray treatments. The interpretation that maturity was only advanced slightly is supported by the fact that the starch–iodine index was not significantly different between the three treatments (Table 1).

Because soluble solids content, blush colour index, and extent of blush coverage all had interactions between the orchards and the treatments, they will be considered together in the discussion. Orchard 3 had the lowest soluble solids content and orchard 1 had the highest of the three orchards, and the white reflective row cover treatment resulted in apples having consistently higher soluble solids contents than the other two treatments (Table 3). Blush colour index was lowest in the control treatment and the greatest variation in blush

Table 4. I_{AD} value, starch–iodine index values, titratable acidity, and firmness of Ambrosia™ apples at harvest from three orchards in Cawston, BC, in 2014.

	I_{AD} (relative values)[a]	Starch–iodine index (1–9 scale)[b]	Titratable acidity (%)	Firmness (N)
Orchard 1	0.65 ± 0.02	4.2 ± 0.2	0.103 ± 0.002	75.3 ± 0.6
Orchard 2	0.53 ± 0.02	4.2 ± 0.1	0.146 ± 0.003	66.9 ± 0.5
Orchard 3	0.64 ± 0.02	3.6 ± 0.2	0.128 ± 0.003	69.3 ± 0.4

Note: Apples were harvested from three preharvest field treatments, which included a non-treated control, two foliar preharvest sprays with Hydrophos™, and the application of a white reflective row cover (Extenday™) 4 wk before harvest. Means are an average three replicates and three treatments ± standard error.

[a]The I_{AD} is a relative measure of chlorophyll content in the apple peel and a decline of relative content is an indicator of Ambrosia™ apple maturity (Toivonen 2015).

[b]The starch–iodine index scale used in this work was established specifically for Ambrosia™ apples and ranges from 1 = completely stained to 9 = completely clear (unstained) (Toivonen 2015).

colour index was within this treatment (Table 3). There were no differences between the blush colour index values for the three orchards in the white reflective row cover and the foliar spray treatments (Table 3), both treatments had higher index values than the control treatment at all three orchards. The extent of blush coverage showed a similar pattern as was seen for the blush colour index over the three orchards in the control treatment, where orchard 2 had the highest value, followed by orchard 3 and then orchard 1 (Table 3). The extent of coverage was highest for apples from the white reflective row cover treatment and orchard 2 had the highest values for that treatment. Extent of coverage was highest in orchard 3 when looking only at the foliar spray treatment (Table 3), suggesting that the row cover and foliar spray treatments had differential physiological effects on processes involved in determining the extent of blush coverage.

The variation in blush colour index and extent of coverage in the control treatment indicated that orchard 2 had better blush colour development than the other two orchards. It was determined after the experiment was completed that orchard 2 had Apogee® applied to control vigor. Apogee® not only controls the growth of new shoots in apples, but it has also been documented to enhance the development of red blush colour (Osborne et al. 2003; Cline et al. 2008). Therefore, the greater blush colour index and extent of coverage in the control treatment in that orchard was expected. However, the application of white reflective row cover or foliar sprays with Hydrophos™ enhanced the red blush even for orchard 2, suggesting that these blush enhancing treatments can be beneficial despite application of other orchard practices that might enhance red blush development in Ambrosia™ apples.

Orchard differences were also found for I_{AD} index values, starch clearing index, titratable acidity, and firmness (Table 4), whereas starch–iodine index, titratable acidity, and firmness at harvest were not affected by the row cover treatments (Table 1). Orchard 2 had the lowest I_{AD} index value with the lowest firmness and highest titratable acidity (Table 4). These results indicate the orchard differences can influence maturity and internal quality measures, perhaps more than the row cover treatments applied in this experiment. As such, the use of white reflective row cover or foliar spray treatments to enhance blush colour development on apples would be considered to be of minor concern in regard to at-harvest apple fruit quality, as is suggested by prior reports (Larrigaudiere et al. 1996; Mathieu and D'Aure 2000; Paliyath et al. 2002; Schmidt et al. 2010).

Table 5. Analysis of variance to determine significance of influence of row cover treatments, orchard effects, storage duration under a controlled atmosphere (1.0 kPa O_2 + 1 kPa CO_2) at 0.5 °C, and their interactions for titratable acidity, soluble solids content, and firmness from an experiment conducted using 1-MCP treated (1 μL L^{-1} 1-MCP for 14 h before storage) Ambrosia™ apples in the 2014 harvest season.

Source	Titratable acidity	Soluble solids content	Firmness
Orchard (O)	<0.0001	<0.0001	<0.0001
Row cover (RC)	0.0001	<0.0001	0.0502
O × RC	0.0008	0.0047	0.1322
Storage duration (SD)	<0.0001	<0.0001	<0.0001
O × SD	0.3605	0.0176	0.0092
RC × SD	0.7169	0.7327	0.4813
O × RC × SD	0.7811	0.2626	0.2381

Post-storage titratable acidity and soluble solids content, however, were affected by row cover treatment as well as by orchard and storage duration (Table 5). Firmness outcomes after 5 and 8 mo of CA storage were only influenced by orchard, storage duration, and their

Table 6. Titratable acidity, soluble solids content, and firmness of Ambrosia™ apples from three growers and three preharvest treatments (control, Extenday™ white reflective row cover, and Hydrophos™ foliar spray) after pre-storage treatment with 1 μL L^{-1} 1-MCP and 5 or 8 mo in controlled atmosphere storage (1.0 kPa O_2 + 1 kPa CO_2) at 0.5 °C.

Storage duration	Control	White reflective row cover	Foliar spray
Titratable acidity (%)			
5 mo			
Orchard 1	0.212 ± 0.004	0.201 ± 0.014	0.200 ± 0.011
Orchard 2	0.278 ± 0.013	0.266 ± 0.010	0.303 ± 0.007
Orchard 3	0.270 ± 0.005	0.237 ± 0.007	0.231 ± 0.007
8 mo			
Orchard 1	0.211 ± 0.004	0.185 ± 0.016	0.192 ± 0.005
Orchard 2	0.278 ± 0.013	0.249 ± 0.010	0.291 ± 0.010
Orchard 3	0.255 ± 0.008	0.222 ± 0.005	0.224 ± 0.016
Soluble solids content (%)			
5 mo			
Orchard 1	11.9 ± 0.2	12.6 ± 0.1	12.6 ± 0.4
Orchard 2	12.0 ± 0.2	12.7 ± 0.3	12.2 ± 0.2
Orchard 3	10.5 ± 0.2	11.4 ± 0.2	11.2 ± 0.1
8 mo			
Orchard 1	11.7 ± 0.1	12.6 ± 0.2	12.6 ± 0.2
Orchard 2	12.0 ± 0.2	12.2 ± 0.1	12.0 ± 0.3
Orchard 3	10.5 ± 0.1	11.4 ± 0.2	11.0 ± 0.1
Firmness (N)			
5 mo			
Orchard 1	79.4 ± 0.3	77.7 ± 0.7	78.2 ± 1.0
Orchard 2	72.7 ± 0.5	70.1 ± 0.6	70.5 ± 0.7
Orchard 3	74.0 ± 0.2	73.9 ± 0.9	73.4 ± 1.3
8 mo			
Orchard 1	77.1 ± 1.0	78.4 ± 0.8	77.4 ± 1.3
Orchard 2	72.7 ± 0.5	68.2 ± 0.8	70.0 ± 1.1
Orchard 3	75.3 ± 0.1	74.3 ± 0.4	76.5 ± 1.4

Note: Apples were removed from storage and held at 20 °C for 1 wk before quality measures were performed. Apples were harvested in 2014 and removed from storage in 2015. Means are an average of four replicates ± standard error.

Table 7. Analysis of variance to determine significance of influence of row cover treatments, orchard effects, and their interactions for sooty blotch and greasiness of 1-MCP treated (1 μL L^{-1} 1-MCP for 14 h before storage) Ambrosia™ apples under a controlled atmosphere (1.0 kPa O_2 + 1 kPa CO_2) at 0.5 ° C for 8 mo.

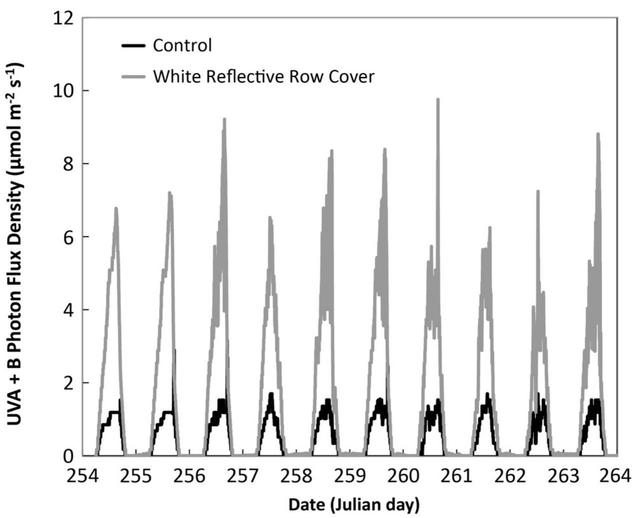
Source	Sooty blotch	Greasiness
Row cover (RC)	<0.0001	<0.0001
Orchard (O)	0.0011	<0.0001
RC × O	0.7970	<0.0001

interaction. Row cover treatment was on the borderline of being significant, but no interaction terms involving row cover as a factor were significant (Table 5). Therefore, it was concluded that of the internal quality measures, only titratable acidity and soluble solids content were affected by row cover treatment. Orchard and storage duration influenced all three measures of internal quality (Table 5).

Firmness was lowest in orchard 2 at the time of harvest (Table 4) and the firmness of Ambrosia™ apples from that orchard continued to be the least firm of the three orchards after 5 and 8 mo of CA storage (Table 6). Titratable acidity was also the highest in apples from orchard 2 at harvest (Table 4) and this difference was maintained over 5 and 8 mo of CA storage (Table 6). There were no consistent patterns of differences in response to red blush enhancing treatment for titratable acidity, soluble solids content, or firmness (Table 6). These results indicate that orchard effects were consistently more important to post-storage internal quality than treatment in enhancing red blush development. Therefore, the approach used to enhance red blush in Ambrosia™ would not be considered critical in regards to post-storage quality after 5 and 8 mo of CA storage.

Post-storage defects were affected by red blush enhancing treatment, as the analysis from the 8 mo CA storage indicated (Table 7). Sooty blotch and greasiness were affected by red blush enhancing treatment and also by orchard. The only significant interaction between red blush enhancing treatment and orchard was found for greasiness (Table 7). Greasiness was not detected in the white reflective row cover or control treatment apples, but was considered to be slight to moderate in severity in the foliar spray treatment apples (Table 7). Sooty blotch, which is a surface mould found in stored apples (Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) 2011), was moderate to severe in foliar spray treated apples and slight to moderate in the control apples. Sooty blotch was barely detected in apples from the white reflective row cover treatment (Table 7). Growth of mould in CA storage is partially encouraged by the fact that the air is nearly at saturated humidity (unpublished data), but there were differences between the red blush enhancing treatments, suggesting that the nature of the treatment conditions in the orchard has an influence on the mould populations on the fruit surface at harvest. The very low levels of sooty blotch in the white reflective row cover treatment may be explained by the fact that this row cover reflects at least three times more ultraviolet light levels onto the tree and the fruit (Fig. 1). The UVB wavelength, as found in normal sunlight exposure, has been shown to be associated with inhibition of spore germination of surface-growing plant pathogenic fungi (such as powdery mildew, for example) (Willocquet et al. 1996) and, therefore, the higher levels in the white reflective row cover treatment may explain the lower occurrence of sooty blotch

Fig. 1. Diurnal reflected photon flux density measured from 11 to 21 Sept. (Julian days 254 to 264) when the row cover treatments were applied. An ultraviolet sensor measuring total flux density between 250 and 400 nm (Model SU-100-SS, Apogee Instruments, Logan, UT) was positioned on an anchored post at a 2 m height in the tree canopy, oriented at a 45° angle down towards the centre of the row. The sensors were shielded to ensure that the only UV light measured was that reflected from the row into the canopy for the control or the reflective row cover treatments. The analog output from these sensors was captured with a data logger (Model CR1000, Campbell Scientific, Edmonton, AB) and the data was subsequently downloaded into Excel for processing.



in apples from that treatment after storage. Similarly, it has been shown that summer pruning, which enhances the light exposure of the fruit (including the ultraviolet spectrum), results in reduced development of sooty blotch in storage (Spolti et al. 2011). The foliar spray contained mostly phosphorus and some magnesium (Paliyath et al. 2002). High levels of phosphorus on the peel surface may have significantly improved nutrition at the peel surface, such that the fungi responsible for sooty blotch were better able to develop during storage (Bhargava and Tandon 1963). Therefore, it is likely that sooty blotch was affected by both exposure of the fruit to ultraviolet light in the field, which reduced fungal survival in the peels, and application of foliar nutrient spray, which would have enhanced the growth of the fungus. The effect of Hydrophos™ on greasiness is explained by the importance of free phosphate in providing the energy required for synthesis of fatty acids (Espino-Díaz et al. 2016) and the fact that greasiness is a result of the accumulation of fatty acids on the surface of the apple peel (Christeller and Roughan 2016). Therefore, the application of a foliar spray such as Hydrophos™ in order to enhance red blush development may lead to an undesirable enhancement of greasiness after long term storage.

Table 8. Incidence of defects for Ambrosia™ apples from three growers and three preharvest treatments (control, Extenday™ white reflective row cover, and Hydrophos™ foliar spray) after treatment with 1 μL L^{-1} 1-MCP and 8 mo of controlled atmosphere storage (1.0 kPa O_2 + 1 kPa CO_2) at 0.5 °C.

	Control	White Reflective row cover	Foliar spray
Greasiness[a]			
Orchard 1	0	0	1.45 ± 0.26
Orchard 2	0	0	0.95 ± 0.05
Orchard 3	0.1 ± 0.1	0	1.68 ± 0.06
Sooty blotch[a]			
Orchard 1	1.3 ± 0.13	0.28 ± 0.09	2.83 ± 0.09
Orchard 2	0.75 ± 0.30	0.18 ± 0.09	2.35 ± 0.21
Orchard 3	0.58 ± 0.21	0.18 ± 0.21	2.63 ± 0.11

Note: Means are an average of four replicates ± standard error.

[a]Sooty blotch and greasiness were rated as: 0 = none, 1 = slight, 2 = moderate, or 3 = severe.

Experiment 2: comparison of reflective row covers to enhance red blush

Use of silvered Mylar® row covers resulted in Ambrosia™ apples having a more advanced maturity at harvest, as indicated by a lower I_{AD} value, and lower firmness and ground colour hue angle (Table 9). I_{AD} values have been found to be more reliable and sensitive to monitoring Ambrosia™ apple maturity than the starch–iodine index in British Columbia (Toivonen 2015), and so it is not surprising that apples from all treatments had similar starch–iodine indices, despite the noted differences in the other maturity indicators discussed above. Blush colour index (red intensity) was similar for apples from the two reflective row cover treatments, but the white reflective row cover treatment resulted in the greatest degree of coverage over the entire apple (Table 9).

After 5 mo of air storage at 0.5 °C, the apples from the silvered Mylar® reflective row cover treatment had lower firmness and titratable acidity and higher soluble solids content and soft scald incidence than apples from the two other treatments (Table 10). Soggy breakdown was only found in apples from the silvered Mylar® row cover treatments (Table 10). These results indicate that apples from the silvered Mylar® row cover treatments were somehow physiologically injured in the field. A consequence was that loss of both firmness and titratable acidity was accelerated and both soft scald and soggy breakdown were accentuated or induced, respectively. Whereas there is no specific published literature in regards to orchard factors that could affect chilling injury development in storage (i.e., soft scald and soggy breakdown), there is evidence in the literature that heat

Table 9. Maturity indices (starch–iodine index, firmness, and I_{AD} index) and quality measures (blush colour index, blush coverage, and ground colour) for Ambrosia™ apples at harvest from one orchard in Cawston, BC, in 2015.

	I_{AD} (relative value)	Starch–iodine index (1–9)	Firmness (N)	Blush colour index[a]	Extent of blush coverage[b]	Ground colour (h°)[c]
Control	0.64 ± 0.04	2.9 ± 0.2	83.7 ± 1.8	28.2 ± 3.2	1.7 ± 0.1	98.0 ± 3.2
Silvered Mylar®	0.37 ± 0.03	3.4 ± 0.2	77.4 ± 0.7	40.6 ± 1.3	3.2 ± 0.1	65.1 ± 5.3
White reflective row cover	0.51 ± 0.04	3.0 ± 0.2	79.9 ± 0.9	38.5 ± 2.0	3.7 ± 0.1	69.2 ± 5.4
Significance	0.0002	0.1929	0.0044	0.0017	<0.0001	<0.0001

Note: Apples were harvested from three preharvest field treatments, which included a non-treated control, application of a silvered Mylar® reflective row cover (Brite-N'up) 4 wk before harvest, and the application of a white reflective row cover (Extenday™) 4 wk before harvest. Means are an average of four replicates ± standard error.

[a]Blush colour index was calculated from *L**, *a**, and *b** values collected using a Minolta Chroma meter with a method adapted from Cliff et al. (2009).

[b]0 = <5% of the apple surface, 1 = 5%–25% of the apple surface, 2 = 25%–50% of the apple surface, 3 = 50%–75% of the apple surface, and 4 = >75% of the apple surface.

[c]Hue angle (h°) was calculated from *a** and *b** values collected using a Minolta Chroma meter with a SAS program developed by McGuire (1992).

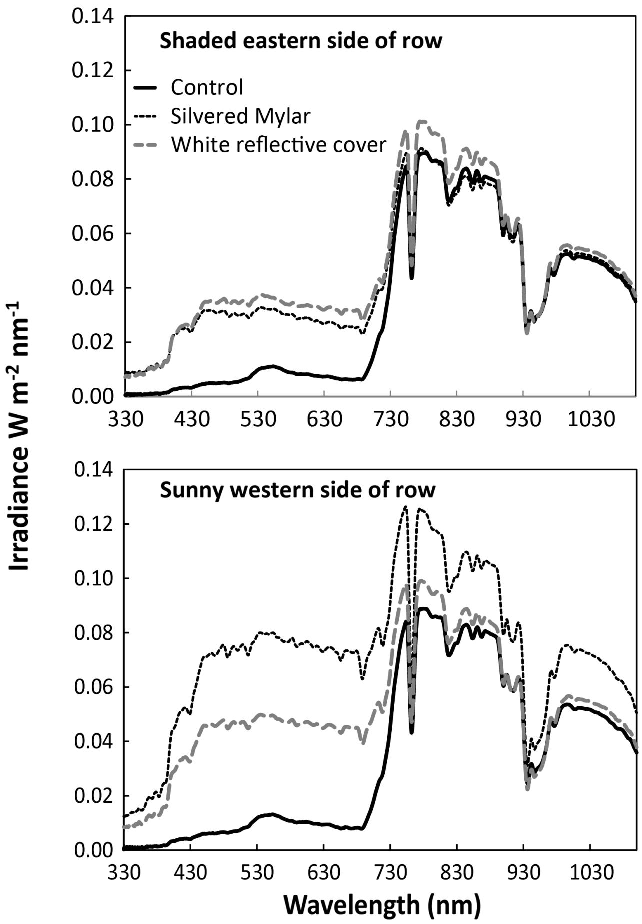
Table 10. Effect of row cover on internal quality and incidence of soft scald and soggy breakdown in Ambrosia apples after 5 mo of air storage at 0.5 °C plus 7 d at 20 °C before quality was assessed.

	Titratable acidity (%)	Soluble aolids (%)	Firmness (N)	Soft acald incidence (ratio)[a]	Soggy breakdown incidence (ratio)[a]
Control	0.23 ± 0.01	13.3 ± 0.1	78.3 ± 0.4	0.17 ± 0.12	0
Silvered Mylar®	0.20 ± 0.01	13.8 ± 0.1	71.6 ± 1.3	0.38 ± 0.02	0.13 ± 0.02
White reflective row cover	0.22 ± 0.01	13.6 ± 0.1	77.8 ± 0.4	0.02 ± 0.02	0
Significance	0.0085	0.0145	0.0019	0.0188	0.0002

Note: Row cover treatments were applied 4 wk before harvest on 15 Sept. 2015 and apples were treated with 1-MCP before storage. Apples were removed from storage on 21 Mar. 2016. Means are an average of four replicates ± standard error.

[a]Ratio between number of apples affected by the disorder and the total number of apples evaluated ($n = 12$).

Fig. 2. Spectra of reflected light from 330 to 1060 nm as measured in the control, white row cover, and silvered Mylar® row cover treatments on 21 Sept. 2015. A portable spectroradiometer (Licor Li-1800, Licor, Lincoln, NE) was set up in the orchards using metal tripod stands to allow measurement of reflected light quality/quantity differences from rows into the canopy. The spectroradiometer was fitted with a quartz fiber optic probe to allow measurement of light reflected from the row into the canopy at a 1 m height. The sensor head was positioned at a 45° angle down towards the row from the canopy and shrouded to eliminate the potential of direct incident sunlight exposure. Data was transferred to Excel.



and water stress increases the severity of another chilling injury, superficial or storage scald (Fidler 1957; Wilkinson and Fidler 1973). Two observations were made that suggest that apples from the silvered Mylar® reflective row cover treatments were subject to greater heat in the fruit and water stress: (*i*) spectroradiometer scans show that greater long-wavelength irradiation (i.e., heat) was reflected by that row cover onto the trees and exposed fruit (Fig. 2), and (*ii*) water from micro-sprinkler irrigation pooled on top of the silvered Mylar® (Fig. 3), whereas water drained into the rows covered with the white woven reflective row cover, as the weave was open such that water could penetrate down to the soil below.

Fig. 3. Photograph of a row in an Ambrosia™ apple orchard covered with a silvered Mylar® material (Brite-N'up, Peaceful Valley Farm Supply, Grass Valley, CA). Note the pooling of water from the micro-sprinkler irrigation system after a watering cycle.

It is likely that the nature of the reflecting properties of the silvered Mylar® row cover and the fact that it is a solid film, preventing water and air penetration to the soil, both contributed to inducing heat and (or) water stress in the apples for 4 wk before harvest, and this was also expressed as an advancement in maturity (Table 9) and consequent lower post-storage quality and expression of chilling injury in the form of soft scald and soggy breakdown (Table 10).

This work clearly demonstrates that the application of preharvest treatments to improve the marketable quality (i.e., red blush) of apples should be evaluated not just at harvest, but also after time in storage. Unintended effects that lower post-storage quality may provide some perspective in terms of which approach is best implemented to achieve at-harvest cosmetic quality while minimizing negative secondary responses in storage.

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