Effect of Particle Film on Fruit Sunburn, Maturity and Quality of 'Fuji' and 'Honeycrisp' Apples

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SUMMARY. Studies were initiated in Idaho and New York to determine the effects of Surround, a kaolin clay particle film product recently labeled as a crop protectant for agricultural crops, on fruit maturity and quality of 'Fuji' and 'Honeycrisp' apples (*Malus × domestica*) and fruit mineral concentration of 'Fuji' apples. Surround reduced fruit weight, red color, and the incidence of sunburn of 'Fuji' apples in Idaho. Sunburn did not occur on 'Honeycrisp' in the New York study. In that study, Surround had no effect on fruit weight or red fruit color when applied in May and June but reduced fruit weight and red color when applied later. The reduction in red color development observed in both 'Fuji' and 'Honeycrisp' was not related to mineral nutrients or to a delay in fruit maturity. Surround applications resulted in undesirable residues in the basin and in the cavity of harvested fruit that were not satisfactorily removed by brushing on a commercial

packing line. While effective for reducing sunburn, Surround was ineffective for increasing red fruit color of apples.

Fuji apple has gained popularity among consumers in recent years because of its pleasant taste and the ability to maintain firmness over a long period both in controlled atmosphere and regular cold storages. 'Fuji' constitutes a large portion of new apple plantings in the Pacific northwestern U.S.; however, producing high-colored (red) 'Fuji' without sunburn is a major challenge for apple growers. 'Fuji' fruit is more prone to sunburn when trees are grown on size-controlling rootstocks. Fruit from trees on more vigorous rootstocks, however, have less sunburn and red color due to the presence of more foliage.

Red color development of 'Honeycrisp' fruit may require temperatures similar to that of 'McIntosh' and other cool climate cultivars where the commercial production of such cultivars is confined to cool apple growing regions. New York's Hudson Valley is considered by many to be the southern limit for good color development of 'McIntosh'. Sunburn and lack of red fruit color reduced packout of 'Honeycrisp' grown in the Hudson Valley in the unusually hot drought year of 1999.

Particle film sprays such as Surround have been recommended to lower the temperature of the fruit, thereby reducing sunburn and improving red fruit color in situations where temperatures are supra optimal (Heacox, 1999; Stanley, 1998; Warner, 2000a; Werblow, 1999). Glenn et al. (2001) reported that kaolin clay particle films reduced heat stress, increased carbon dioxide (CO₂) assimilation, increased fruit yield and/or size, and in some cases, increased red fruit color.

The additional costs associated with such treatments may be justified with a high-value, low-coloring cultivar, if it results in increased crop value. To test this hypothesis two studies were conducted in 2000 to determine the effect of Surround on sunburn, color and maturity of 'Fuji' apple in Idaho and 'Honeycrisp' apple in New York.

Materials and methods

IDAHO EXPERIMENT. The plants in this experiment were 6-year-old 'Fuji' (strain TAC-114) apple trees on

Malling 26 EMLA (M.26 EMLA) and Budagovski 118 (B.118) rootstocks planted at 8 × 18 ft (2.4 × 5.5 m) spacing at University of Idaho Parma Research and Extension Center, Parma, Idaho. There were several groups of trees on each row. Each group consisted of two trees on either M.26 EMLA or B.118, scattered randomly along the row. Four random groups of trees on M.26 EMLA and four random groups on B.118 rootstock were sprayed with Surround (Engelhard Corp., Iselin, N.J.) on 10, 17, and 24 July 2000, while four groups of trees on each rootstock were not sprayed and were used as control. Therefore, the experimental arrangement for each rootstock was a completely randomized design with eight trees per treatment. Since no significant interaction was detected between rootstock and spray treatment, values were pooled to test the effect of rootstock and spray treatments.

The rate of Surround was 50 lb (22.7 kg) in 200 gal (757.1 L) of water. In each application, Surround was applied with an air-blast sprayer calibrated to apply 200 gal/acre (1870 L·ha⁻¹). Several buffer trees were used to prevent overspray between sprayed and nonsprayed trees.

Trees were trained to the central leader system, and supported with individual wooden stakes. Mineral nutrients were applied by fertigation through a microjet irrigation system. Other cultural practices were applied in a manner consistent with those of commercial 'Fuji' orchards.

Fruit sunburn status was visually estimated as the percentage of sunburned fruit on each tree relative to the total number of fruit on the tree just before harvest. Yield was recorded for each tree. Eighteen fruit were randomly sampled from each tree on 27 Oct. 2000. Fruit were weighed and fruit color was visually ranked on a scale of 1 to 5, with 1 = 20% red progressively to 5 = 100% red. From these 18 fruit, eight fruit per tree were used for measuring fruit quality attributes (firmness, soluble solids concentration, and starch index) and five were used for mineral analysis. The remaining five fruit were measured for respiration activity in respiration chambers. Soluble solids concentration (SSC) was measured by temperature-compensated refractometer (Atago NI; Tokyo, Japan). Fruit firmness was

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measured with a fruit texture analyzer (Guss, Strand, Western Cape, South Africa). Starch degradation pattern (SDP) of equatorial slices of each fruit was recorded by comparison with the SDP standard chart developed for apples (Bartram et al., 1993).

Five fruit per tree were washed with a mild detergent solution and rinsed in deionized water. Each fruit was peeled and cut longitudinally to collect flesh and peel tissues. Tissues were dried at 149 °F (65 °C), and ground to pass through a 40-mesh screen. Nitrogen concentration of each sample was measured by a protein/nitrogen analyzer (model FP-528; LECO Corp., St. Joseph, Mich.). Concentrations of calcium and magnesium were measured by atomic absorption spectrophotometry (1100 B; Perkin-Elmer, Norwalk, Conn.) as described by Jones (1977).

To evaluate the effect of Surround on fruit maturity, five apples from each tree were weighed and then placed in 7.9 × 11.0 × 11.2-inch (20 × 28 × 28.5-cm) closed chambers. The temperature of the chambers was maintained at 73 °F (22.8 °C). Air samples with a constant flow rate of 0.021 gal/min (80 mL·min⁻¹) were drawn from the ripening chambers every 24 h to measure concentrations of evolved ethylene and CO₂ by gas chromatography. Samples were injected onto a gas chromatograph (5890 Series II; Hewlett Packard, Lionville, Pa.) equipped with a flame ionization detector and a HayeSep Q, 80/100 packed column (Alltech Inc., Deerfield, Ill.).

Assumption of normality was checked by computing univariate analyses for all treatments of this study. All data were normally distributed including percentages of sunburn rates. Data were analyzed by general linear analysis (GLM) and Duncan's new multiple range test ($P \leq 0.05$) using SAS (SAS Institute Inc., Cary, N.C.).

NEW YORK EXPERIMENT. Six-year-old 'Honeycrisp' / M.26 EMLA apple trees growing in a commercial orchard in Milton, N.Y. at 8 × 16 ft (2.4 × 4.8 m) spacing were used for this experiment. Trees were trained to the vertical axis system and were trickle irrigated. Mineral nutrients, herbicides, pesticides and all other cultural practices were applied in a manner consistent with best management practices.

Ten-tree plots were treated as follows: 1) untreated control; 2) Surround applied weekly from 15 May to 26 June (Surround-early); 3) Surround applied weekly from 6 July to 17 Aug. (Surround-late). Each spray of 50 lb Surround in 200 gal of water was applied with an air-blast sprayer calibrated to apply 200 gal/acre. Several buffer trees were used to prevent overspray between sprayed and nonsprayed trees. Treatments were arranged in a randomized complete block design with six replications.

On 1 Sept., a 50-fruit sample was collected from the central trees in each plot for evaluation of fruit weight, fruit color, and fruit maturity. All 50 fruit were weighed and visually rated for the percentage of the surface covered with red blush. Lightness (L value), saturation (chroma), and hue angle of the

blushed and nonblushed side of 40 fruit were characterized using a chromameter (CR-300; Minolta Corp., Ramsey, N.J.) equipped with a data processor (DP-301; Minolta). Color descriptors for the blushed side were used to evaluate the effects of treatment on red color development, while those for the nonblushed side were used to evaluate chlorophyll disappearance, a fruit maturity indicator. Leaf chlorosis observed among the plots was rated on 10 Aug., using a 1 = none to 5 = 100% scale.

Maturity of 10 fruit was further evaluated by measuring the internal ethylene concentration by gas chromatography, and by rating SDP. A 1-mL sample of air from the core cavity of each apple was injected into a gas chromatograph (5890 Series II; Hewlett Packard) equipped with a flame ionization detector and an activated alumina column. SDP of equatorial slices of each fruit was recorded by comparison with a generic starch-iodine chart developed for apples (Blanpied and Silsby, 1992).

Assumption of normality was checked by computing univariate analyses for all treatments of this study. All data were normally distributed. Data were analyzed by ANOVA and Duncan's new multiple range test ($P \leq 0.05$) using SAS (SAS Institute Inc., Cary, N.C.).

Results and discussion

IDAHO 'FUJI' EXPERIMENT. There were no interactions between rootstock and spray treatment, therefore the values were pooled and the main-

Table 1. Effect of Surround on yield and fruit quality of 'Fuji' apple trees on Budagovski 118 (B.118) and Malling 26 EMLA (M.26 EMLA) rootstocks in Idaho (1.00 kg = 2.205 lb; 1.0 g = 0.035 oz). Treatments (T): control and 50 lb/200 gal (22.7 kg/757.1 L) of three application of Surround; rootstock (R): B.118 and M.26 EMLA.

Treatment	Yield (kg/tree)	Avg fruit wt (g)	Fruit				
			Color rating (1-5)	Soluble solids (%)	Firmness (kg)	SDP ^y	Sunburn rate (%)
Control	31.46 a ^z	224.6 a	3.30 a	13.08 a	7.26 a	4.65 a	27.9 a
Spray	32.31 a	194.6 b	2.61 b	12.63 a	7.12 a	5.01 a	6.0 b
B.118	41.15 a	219.2 a	2.85 a	12.67 a	6.93 b	4.87 a	8.9 b
M.26	19.83 b	194.8 a	3.03 a	13.06 a	7.54 a	4.80 a	25.8 a
Significance							
T	NS	*	*	NS	NS	NS	***
R	***	NS	NS	NS	**	NS	***
T × R	NS	NS	NS	NS	NS	NS	NS

^zMean separation by treatment category and within columns by Duncan's multiple range test at $P \leq 0.05$.

^yStarch degradation pattern.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.001 or 0.0001, respectively.

Table 2. Effect of Surround on fruit nitrogen (N), calcium (Ca), and magnesium (Mg) concentration of 'Fuji' apple trees Budagovski 118 (B.118) and Malling 26 EMLA (M.26 EMLA) rootstocks in Idaho. Treatments (T): Control (no spray) and 50 lb/200 gal (22.7 kg/757.1 L) of three application of Surround; rootstock (R): B.118 and M.26 EMLA.

	Element concn (based on dry wt)					
	Fruit peel			Fruit flesh		
	N (%)	Ca (%)	Mg (%)	N (%)	Ca (%)	Mg (%)
Control	0.329 a ^z	0.082 a	0.094 a	0.240 a	0.016 a	0.019 a
Spray	0.359 a	0.091 a	0.097 a	0.264 a	0.017 a	0.021 a
B.118	0.349 a	0.091 a	0.098 a	0.248 a	0.018 a	0.023 a
M.26 EMLA	0.339 a	0.081 a	0.093 a	0.257 a	0.015 a	0.018 b
Significance						
T	NS	NS	NS	NS	NS	NS
R	NS	NS	NS	NS	NS	*
T × R	NS	NS	NS	NS	NS	NS

^zMean separation by treatment category and within columns by Duncan's multiple range test at $P \leq 0.05$.

NS,*Nonsignificant or significant at $P \leq 0.05$, respectively.

effect means of each treatment are reported. Surround reduced fruit weight, color, and percentage of sunburn (Table 1), but had no effect on yield per tree, SSC, SDP, firmness or mineral concentrations of fruit peel and flesh tissues of 'Fuji' apples (Tables 1 and 2). Respiration and ethylene evolution of 'Fuji' apples were not influenced by Surround (Fig. 1). Our results agree with those of Glenn et al. (2001) who reported that applications of Surround after July had little effect on yield of 'Delicious' apples.

'Fuji' trees on B.118 had greater yield per tree than did those on M.26 EMLA (Table 1) due to the larger tree canopy of trees on B.118. Rootstock had no effect on mineral concentrations of fruit peel of 'Fuji' apples (Table 2). M.26 rootstock reduced Mg concentration of flesh tissues. Fruit from trees on M.26 EMLA were firmer and had higher incidence of sunburn than that from trees on B.118 rootstock, perhaps because fruit on M.26 EMLA were more exposed to light than those on B.118.

NEW YORK 'HONEYCRISP' EXPERIMENT. Although 'Honeycrisp' is very sensitive to sunburn, none occurred in this trial (data not presented). Cool weather experienced in eastern New York during much of the 2000 season was not favorable to sunburn formation. The Surround-late treatment reduced fruit weight, amount of blushed fruit surface, and color saturation (chroma) on the blushed side of the fruit (Table 3). Hue angle of Surround-late fruit was greater (less red) than that of the controls. Both Surround treatments reduced the severity of leaf chlorosis on 'Honeycrisp'.

Surround had no effect on fruit internal ethylene concentration and SDP rating, or on the L value or chroma of the nonblushed side of the fruit (Table 4). Hue angle of the nonblushed surface of Surround-late fruit was greater (more green) than that of Surround-early fruit, although neither Surround treatment

differed from that of the controls.

In our studies, application of Surround after June reduced fruit weight of 'Fuji' and 'Honeycrisp' by 13% and 12%, respectively. This size reduction could very likely result in a loss of return to growers and the loss could be even more severe in small-fruited cul-

Fig. 1. Effect of Surround on (A) respiration [carbon dioxide (CO₂)] and (B) ethylene evolution (C₂H₄) of 'Fuji' apples in Idaho. For both respiration and ethylene, means of control and sprayed fruit within each sampling day were always statistically similar at 5% level.

Table 3. Effect of early or late season Surround kaolin clay applications on fruit weight, fruit color, and leaf chlorosis of 'Honeycrisp' apple in New York (28.4 g = 1.0 oz).

Treatment	Fruit wt (g)	Blush (%)	Red color		Hue angle	Leaf chlorosis rating ^y
			L value	Chroma		
Control	214 a ^z	59 a	44	37	34 b	3.0 a
Surround						
Early	208 ab	60 a	43	37	35 ab	1.9 b
Late	188 b	46 b	47	35	44 a	1.9 b

^zMean separation by Duncan's multiple range test, $P \leq 0.05$.^yScale from 1 = 100% green to 5 = 100% yellow.**Table 4. Effect of early or late season Surround kaolin clay applications on fruit maturity indices of 'Honeycrisp' apple in New York.**

Treatment	Internal ethylene concn [mL·L ⁻¹ (ppm)]	Starch Index	Ground color		
			L value	Chroma	Hue angle
Control	27	7	70	44	107 ab ^z
Surround					
Early	24	7	70	44	106 b
Late	27	7	70	45	109 a

^zMean separation by Duncan's multiple range test, $P \leq 0.05$.

tivars, such as 'Empire' or 'Gala'. Glenn et al. (2001) previously reported that kaolin clay particle films increased fruit size in four of seven experiments, with no effect on size in three experiments. All but one of the studies reported in their report were carried out under environmental conditions with temperatures $>86^{\circ}\text{F}$ (30°C) and with trees exhibiting heat stress. Under such conditions, temperature, not light would limit assimilation (A). Under less stressful temperatures, Glenn et al. (2001) showed that kaolin sprays reduced A, presumably due to reduced light reaching the leaf surface (Glenn et al., 1999). Further studies of the timing and frequency of kaolin clay applications on different apple cultivars and in different climatic conditions need to be done to better understand these conflicting results.

Surround applied in May and June had no effect on fruit color of 'Honeycrisp' apples, while Surround applications beginning in July reduced red fruit color on both 'Fuji' and 'Honeycrisp'. Surround had no effect on fruit mineral nutrient concentration or maturity in either study, thus, the reduction in red color development we observed in both 'Fuji' and

'Honeycrisp' was not related to mineral nutrients or to a delay in fruit maturity.

Later applications of Surround in July (Idaho) and in July and August (New York) were timed to reduce sunburn, in accordance with the label recommendations. While very effective for this purpose (Table 1), this timing resulted in less of the skin surface that was red, and also in a less red hue on the blushed portion of the skin (Tables 1 and 3). Reductions in fruit color and size in our study are possibly due to an increase in the amount of reflected light (Glenn, et al., 1999), resulting in shading of the leaves and fruit. Surround reduced fruit size and color in New York under environmental conditions where light was more likely to be limiting to CO_2 assimilation and red color development than was high temperature. Glenn, et al. (2001) showed no increase in assimilation, fruit size or fruit color in studies where the trees were not exhibiting heat stress.

Discussions with the grower co-operator in New York revealed that Surround applications resulted in undesirable residues at harvest that were not satisfactorily removed by brushing

on a commercial packing line (J. Crist, personal communication). Following such brushing, residues in the basin and in the cavity (the depressions around the stem and the calyx, respectively), had to be removed manually. Difficulty in removing these residues from these depressions on the fruit has also been seen as a problem in Washington (Warner, 2000b).

These results suggest that Surround is ineffective for increased red fruit color development of apples. Particle film sprays in our studies resulted in smaller fruit. Furthermore, while Surround was effective for reducing sunburn, study is needed to find residue removal methods that are both economical and effective.

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