Infrequent Occurrence of Peach Skin Streaking and the Role of Rainwater Attributes on Symptom Development

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Abstract

Streaks lacking pigmentation have impacted red blush cultivars of peaches in many East Coast production areas, but the underlying cause is still unclear. Some evidence suggests that streaking may be caused by reactive agents in rainwater. Peach skin streaking was monitored over two consecutive years at a commercial farm with a history of streaking problems located near Ridge Spring, SC. Six cultivars (two early season, two midseason, and two late season) were evaluated, each in two locations (LocA and LocB). Among those 12 experimental block cultivars, streaking occurred only in 2017 in cv. Scarletprince of LocA with an incidence of 6%. That same year two nearby nonexperimental blocks with 'Scarletprince' revealed 11 and 25% streaking. Streaking was also monitored at the Musser Fruit Research Center (MFRC) in Seneca, SC. At that location, a high incidence of streaking was observed, with 50 and 64% in 'Julyprince' (2017) and 'Carored' (2018), respectively. Rainwater pH taken from each of the 12 experimental blocks ranged from 3.03 to 7.4, ozone (O₃) levels ranged from <0.02 to 0.37 mg/liter, and chlorine (Cl₂) and chlorine dioxide (ClO₂) levels were either just above or under the detection limit of 0.01 mg/liter and 0.02 mg/liter, respectively.

Although the electrical conductivity (EC) was below 100 µS/cm on average, we did measure EC values as high as 1,500 µS/cm. For all samples, the oxidation-reduction potential (ORP) ranged from 90 to 302 mV, indicating oxidizing conditions. Fruit harvested 1 or 2 weeks prior to commercial maturity and treated with solutions of high (10) or low (3) pH, ozone >0.37 mg/liter, and EC values of up to 3,000 µS/cm did not produce symptoms. However, streaking was reproduced with collected rainwater, but the remaining sample volume did not allow further analyses. Using 0.05% ClO₂ to induce streaking, we show that fruit of different cultivars varied in susceptibility when treated 1 week prior to commercial maturity, with 'Juneblade' being the most susceptible and 'August Lady' being the least susceptible. Our study shows that multiple factors determine the occurrence of streaking in peach orchards, including cultivar susceptibility, ripening stage, and the presence of rainwater with sufficient amounts of a yet unknown reactive agent or agent combination.

Keywords: abiotic, tree fruits, epidemiology, climate/weather effects

Peach fruit appearance, aka "finish," greatly influences consumer acceptance and marketability. Final fruit quality is affected by all decisions and practices throughout production from site and cultivar selection to postharvest handling (Crisosto et al. 1995). Because of consumer preference, the peach industry prefers to grow large, red fruit. To make fruit suitable for postharvest handling and to avoid blemishes during transportation, the fruit must be firm when picked (Layne 2007). Fruit of poor quality, including smaller and misshapen fruit, is likely to get a reduced price or may even get rejected by the retailer. Peach skin discolorations, such as inking (Crisosto et al. 1999), skin burning (Cantín et al. 2011), and suture red spot (MacLean et al. 1984) impair fruit finish and lower marketability.

Peach skin streaking is another form of skin discoloration and was only recently described in the scientific literature (Hu et al. 2017). It was first observed in 2003 at a fruit research station near Byron, GA (P. Brannen, UGA, *personal communication*). Since then streaking has become more prevalent and in some years has become a major issue for South Carolina growers. Substantial damage in multiple cultivars was reported in 2015 and 2016, and depending on location and cultivar, streaking severity varied from barely visible to necrotic

streaks (unpublished data). Peach fruit with streaking was also reported in Pennsylvania and Maryland peach orchards as recently as 2018 (M. Shannon, *personal communication*).

Streaking affects red-blush cultivars in both conventional and organic production, essentially eliminating synthetic pesticides as possible contributors (Hu et al. 2017). Streaks can be faint yellow, solid yellow, or even necrotic brown in color, extending in general from the stem of the fruit to the tip end following the flow of liquid over the fruit surface. Fruit with solid yellow or necrotic brown stripes are unmarketable. Symptoms on fruit have not been associated with foliar damage, and underlying causes of peach skin streaking are still unknown. Based on field observations, the occurrence of preharvest streaking was associated with light rain 1 to 2 weeks prior to harvest preceding a period of drought of about 10 days (Hu et al. 2017). Rainwater may therefore concentrate atmospheric pollutants at high enough doses to damage peach skin.

Multiple attributes of rainwater have been shown to cause harm to plant tissue. The pH of rainwater may cause epidermal defects, reductions in crop yield (Proctor 1983; Rinallo and Modi 1995), and discoloration of peach skin in association with ionic contaminants (Cheng and Crisosto 1994). The stability of anthocyanins, which are increasingly synthesized during peach fruit maturation, is also highly dependent on pH (Torskangerpoll and Andersen 2005). Chlorine in irrigation water has also been reported to induce stunting and foliar damage on several nursery crops (Cayanan et al. 2008). Ozone (O₃) causes leaf injury and impaired growth of several crops, including tomato and rice (Sawada and Kohno 2009; Wohlgemuth et al. 2002). Finally, there is a possibility that leaf exudates concentrated in rainwater may be responsible for streaking symptoms.

The objectives of this study were to (i) monitor the occurrence of peach skin streaking over two consecutive seasons in multiple cultivars at a commercial farm in South Carolina; (ii) determine the distribution of streaking within a canopy; (iii) monitor chemical attributes in rainwater suspected to be streaking agents over the course of the peach fruit ripening season and assess their ability to

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produce streaking on peach fruit; and (iv) assess the influence of ripening stage on the susceptibility of peach fruit to streaking.

Materials and Methods

Experimental locations. Six peach cultivars, including ‘Blazeprince’ (ripening late June), ‘Scarletprince’ (ripening early July), ‘Redskin’ (ripening mid-July), ‘O’Henry’ (ripening late July), ‘August Lady’ (ripening early August), and ‘September Sun’ (ripening mid-August), were monitored for streaking in two different locations (LocA and LocB) at a commercial farm in South Carolina. LocA was near Trenton (33°45′36.4″ N, 81°49′08.0″ W), and LocB was near Ridge Spring (33°51′09.1″ N, 81°40′30.9″ W). The orchards (referred to as experimental blocks) in LocA and LocB were clustered within a 10- and 16-km-diameter circle (referred to as cluster), respectively, and the two clusters were separated by at least 6 km. According to the farm operator, some experimental block cultivars near Trenton (LocA) exhibited streaking symptoms in previous years that rendered many fruit unmarketable. Both experimental blocks received the same pesticide treatments in both years for pest and disease management starting with oil sprays at dormancy and ending with preharvest applications for brown rot management. In addition, peach cultivars at the Musser Fruit Research Center (MFRC) in Seneca, SC (34°36′11″ N, 82°52′43″ W) were monitored for streaking occurrence. This research station is located 160 km northwest of the commercial farm. All locations were monitored throughout the growing seasons of 2017 and 2018. The trees used for this study were all 6 to 8 years old and in full production.

Assessment of streaking occurrence. Fruit were examined weekly for streaking symptoms starting 4 weeks prior to harvest. For each experimental block cultivar, streaking incidence was determined on 50 arbitrarily selected fruit per tree for 5 single trees with at least 2 buffer trees between each experimental tree. To assess distribution of streaking within the tree canopy, incidence was recorded for fruit at the top, bottom, inside, and sides of the canopy. For each position, 25 fruit were arbitrarily selected and evaluated.

Rainwater analysis. Rainwater was collected from each experimental block, and attributes, including pH, electrical conductivity (EC), oxidation-reduction potential (ORP), chlorine species (Cl_2 , ClO_2), and ozone (O_3), were assessed for their ability to cause streaking symptoms. AcuRite rain gauges (12.5 cm; Chaney Instrument Co., Lake Geneva, WI) as well as polyethylene bins (7.5 L, 24 cm; Lowe’s Companies, Inc., Mooresville, NC) were set up in each experimental block to measure precipitation and collect rainwater for analysis. Collection bins were examined for rain twice a week or when forecasts predicted a 30% or greater chance of rain starting 4 weeks prior to harvest. The frequent collection schedule was implemented to minimize potential impacts of temperature and light on the rainwater chemistry. At each inspection, the bins were cleaned with DI water. Rainwater was transferred into 500-ml polyethylene bottles (SKS Bottle and Packaging, Inc., Watervliet, NY) and placed on ice for transportation. Samples were analyzed at room temperature within 24 h of sampling. Oxidation reduction potential (ORP), electrical conductivity (EC), and pH were determined in a 100-ml aliquot. ORP was measured using the RE300 ExStik ORP meter (Extech Instruments, Nashua, NH). EC and pH were measured using the pH/conductivity tester PHH-7200 (Omega Engineering, Surrey, UK). Rain samples and leaf rinsate exhibiting low ionic strength (less than 100 $\mu\text{S}/\text{cm}$) were treated with pHisa ionic strength adjustor (Thermo Scientific, Waltham, MA) for improved accuracy and stability. The EC electrode was calibrated according to manual instructions, and pH electrode was calibrated using Orion pure water pH buffers (Thermo Scientific, Waltham, MA). Instruments were calibrated weekly. Chlorine species (Cl_2 , ClO_2) and ozone (O_3) in rainwater were quantified with the AQUAfast AQ3700 colorimetry meter (Thermo Scientific, Waltham, MA) and respective test reagents AC2070 for Cl_2 , AC2099 for ClO_2 , and AC3048 for O_3 (Thermo Scientific Orion, Waltham, MA).

Preparation of leaf rinsate. Leaf samples were collected from experimental block cultivars after at least 10 days of no rain to investigate the potential for leaf rinsate to cause streaking symptoms. Ten

leaves closest to the fruit were collected from five trees, totaling 50 leaves per block. Leaf samples from the 6 experimental block cultivars within LocA were pooled, and so were leaf samples within LocB to yield 300 leaves for each of the two locations. Each leaf collection was rinsed by adding 50 leaves at a time to 250 ml of distilled water in a 500-ml flask with screw cap. Then the flask was inverted several times for 30 s. Rinsed leaves were removed from the rinsate, and a fresh set of 50 leaves was added to the same liquid until 300 leaves were processed. The LocA and LocB rinsate was examined separately for the ability to cause streaking symptoms on detached, immature fruit.

Generation of streaking symptoms on immature fruit. Fruit were harvested 1 and 2 weeks prior to commercial maturity for detached fruit experiments in the laboratory. The ripening status was estimated based on visual assessments during fruit maturation. Fruit used for experiments were collected from the commercial farm and included fruit from ‘August Lady’, ‘Blazeprince’, ‘Fireprince’, ‘Gloria’, ‘Julyprince’, ‘Juneblade’, ‘O’Henry’, ‘Redglobe’, ‘Redskin’, ‘Scarletprince’, and ‘September Sun’. Sodium chloride (NaCl; Fisher Scientific, Hampton, NH) was evaluated at concentrations of 700 $\mu\text{g}/\text{ml}$ and 1,500 $\mu\text{g}/\text{ml}$. These were chosen based on EC value extremes detected in rainwater samples. Chlorine dioxide solutions were generated according to Hu et al. (2017) using the Aquamira Chlorine Dioxide Water Treatment kit (Aquamira Technologies, Inc., Logan, UT). Equal amounts of solutions part A and part B were mixed for 5 min to generate 1% active ClO_2 , which was further diluted to 0.05% (500 $\mu\text{g}/\text{ml}$). The concentration of ClO_2 was chosen based on Hu et al. (2017), who reported ClO_2 at concentrations of 0.02% induced streaking symptoms on immature peach fruit. Water solutions were adjusted to pH 3 and pH 10 using sulfuric acid (H_2SO_4 ; VWR, Radnor, PA) and sodium hydroxide (NaOH; Fisher Scientific, Hampton, NH), respectively. To examine possible combination effects, mixtures of 700 $\mu\text{g}/\text{ml}$ NaCl + pH 3 solution, 700 $\mu\text{g}/\text{ml}$ NaCl + pH 10 solution, 500 $\mu\text{g}/\text{ml}$ ClO_2 + pH 10 solution, 1,500 $\mu\text{g}/\text{ml}$ NaCl + 500 $\mu\text{g}/\text{ml}$ ClO_2 , and 1,500 $\mu\text{g}/\text{ml}$ NaCl + 500 $\mu\text{g}/\text{ml}$ ClO_2 + pH 10 were also applied. Additional treatments consisted of leaf rinsate. Treatments were applied to three equally distant spots on the fruit starting from the shoulder of the stem end using a 1,000 μl pipette (Eppendorf, Hamburg, Germany). A total of 300 μl of treatment solution was pipetted onto the fruit surface as droplets in a single drip line. To ensure slow droplet run-off, a nonionic surfactant (INDUCE; BASF, Ludwigshafen, Germany) was added at 0.125% to all solutions, including the water control. The addition of a surfactant to the individual treatments increased retention and made the drops stick to the fruit simulating slow run-off in the field. The surfactant did not cause symptoms by itself. Three single-fruit replicates were used per treatment, and each experiment was repeated at least once. All treatment solutions were prepared immediately prior to application. Pictures of experimental fruit were taken every 24 h after treatment for 7 days.

The ability of ozone (O_3) to generate streaking was evaluated in a separate study. The trials were conducted in the early morning hours from 5 A.M. to 6 A.M. to ensure slow drying conditions. Immature fruit, 1 and 2 weeks shy of commercial maturity, of ‘Cresthaven’ were subjected to ozone treatments at a concentration of 0.3 $\mu\text{g}/\text{ml}$. A leaf was mounted on each experimental fruit vertically and tip pointing to the fruit using a metal mesh wire contraption. That allowed treatment solutions to persistently run over the fruit surface. The mounted leaves were misted with a hand-held sprayer to run-off and rewetted every 10 to 15 min for 60 min to ensure a constant supply of spray solution drip. Ozone treatments were generated in 250 ml distilled water using the Aqua-6 Ozone Generator (A2Z Ozone Inc., Louisville, KY). Ozonation was conducted for 2 min within 10 min of the first application. Each treatment was conducted on five trees with three single-fruit replicates per fruit for each maturity stage. The experiment was repeated.

Statistical analysis. Using JMP Pro version 14.1.0 (SAS Institute Inc., Cary, NC), we tested for relationships between precipitation and rainwater attributes. Simple linear regressions were evaluated between (i) precipitation and pH, (ii) precipitation and

electrical conductivity, (iii) precipitation and oxidation/reduction potential, (iv) precipitation and chlorine, (v) precipitation and chlorine dioxide, and (vi) precipitation and ozone at $P < 0.05$. To confirm significant relationships, correlation analysis was estimated by Row-wise method for precipitation and O_3 , and REML method for precipitation and ORP. ANOVA analysis was used to determine a relationship between reproduction of streaking and ripening status of peach fruit. Where relationships were significant ($P < 0.05$), we compared means between cultivars using Fisher's LSD student's t test.

Results

Streaking occurrence and incidence in 2017 and 2018 growing season. Streaking was only observed in the experimental block 'Scarletprince' of LocA in 2017 with 6% incidence. None of the other experimental block cultivars in LocB exhibited streaking. However, streaking with incidences of 11 and 25% was observed in two nonexperimental blocks with 'Scarletprince' situated within LocA that same year. Streaking was not observed in either block in 2018; however, a nonexperimental block with 'Harvester' located within LocB exhibited 23% streaking. At the MFRC in Clemson, SC mild streaking occurred on multiple cultivars, including 'Scarletprince', 'August Prince', and 'O'Henry' (J. C. Melgar, Clemson, *personal communication*), but the highest incidence was observed in midseason 'Julyprince' in 2017 (50% incidence) and in early-season 'Carored' in 2018 (64% incidence).

Distribution of streaking within single tree canopies. Distribution of streaking within single tree canopies differed between locations. In the commercial orchards, fruit from the top and canopy

Fig. 1. Distribution of streaking within single tree canopies (bars) and cumulated precipitation (open circle) 7 days prior to symptom development in cvs. Julyprince and Carored at Musser Fruit Research Center (MFRC) and cv. Scarletprince at a commercial farm near Ridge Spring, South Carolina.

sides were predominantly affected, while symptomatic fruit were distributed uniformly within the canopy at the MFRC (Fig. 1). 'Scarletprince' and 'Harvester', which were in nonexperimental blocks near LocA and LocB, revealed streaking distribution patterns within single tree canopies similar to 'Scarletprince' (data not shown). Locations with uniform streaking distribution within single tree canopies received more precipitation during the week prior to symptom development compared with the locations where fruit at the top and canopy sides were predominantly affected (Fig. 1).

Analysis of rainwater from peach orchards. A total of 205 rainwater samples were taken from 12 experimental blocks in 2017, and 2018 between mid-May and mid-August and examined for pH, Cl_2 , and ClO_2 content. Average seasonal pH values ranged from 5.18 to 6.38 between locations in 2017 and from 4.90 to 6.55 in 2018 (Table 1). In both years, the median pH of all samples compiled was greater than 5.85. The minimum pH value recorded was 4.1 in 2017 and 3.03 in 2018, while the maximum pH value was 7.4 in 2017 and 7.01 in 2018 (Table 1). In both years, levels of chlorine (Cl_2) and chlorine dioxide (ClO_2) were either below or just above the detection limit of 0.01 mg/liter and 0.02 mg/liter, respectively (Table 1). Additionally, EC, ORP, and O_3 were determined for samples collected in 2018. Average seasonal EC values ranged from 0 to 60 $\mu S/cm$ between locations. However, we observed individual EC values as high as 1,505 $\mu S/cm$ (Table 2). The ORP of all rainwater samples was positive, indicating oxidizing conditions, but did not exceed 300 mV (Table 2). Simple linear regression revealed a significant effect of precipitation on ORP ($P < 0.05$). Further statistical analysis showed that precipitation and ORP were negatively correlated with a correlation coefficient of -0.212 based on REML method.

Similar to chlorine species, O_3 levels were either below or just above the detection limit of 0.02 mg/liter on average per location (Table 2), but there was a significant ($P < 0.05$) relationship between precipitation and O_3 . A positive correlation was estimated to be 0.3643 by Row-wise method. There were no significant relationships between precipitation and pH, EC, Cl_2 , or ClO_2 , respectively ($P < 0.05$). Analysis of leaf rinsate after periods of drought revealed an average pH of 5.01 and 5.22, average EC of 13 and 23 $\mu S/cm$, and average ORP of 173 and 163 mV for locations A and B, respectively (data not shown). For both locations (A and B), average values of Cl_2 , ClO_2 , and O_3 were under the respective detection limits 0.01, 0.02, and 0.02 $\mu g/ml$, respectively (data not shown).

Development of streaking symptoms and relationship to ripening status of peach fruit. Rainwater attributes including pH and EC extremes as well as leaf rinsate did not cause symptoms on detached fruit picked 1 and 2 weeks prior to harvest (Table 3). Likewise, neither NaCl at concentrations of 700 $\mu g/ml$, solutions of pH 3 or 10,

Table 1. Precipitation, pH, chlorine (Cl_2), and chlorine dioxide (ClO_2) in rainwater collected over 2 years from 12 experimental blocks of a commercial farm in South Carolina

Location within commercial farm	Cultivar	Weekly precipitation (mm)	Total precipitation (mm)	pH	pH range ^a	Cl_2 ($\mu g/ml$)	ClO_2 ($\mu g/ml$)
Location A	Blazeprince	29.97 / 25.91 ^b	298 / 311	6.07 / 5.55	4.7-6.9 / 3.0-6.5	0.02 / <0.03	<0.02 / <0.03
	Scarletprince	14.48 / 32.77	145 / 394	6.34 / 5.81	5.1-7.4 / 3.7-7.0	0.03 / <0.01	<0.02 / <0.02
	Redskin	42.67 / 29.21	425 / 349	5.89 / 4.90	4.7-6.6 / 3.9-5.9	0.02 / <0.01	<0.02 / <0.02
	O'Henry	14.99 / 23.88	149 / 286	6.38 / 5.79	5.9-6.9 / 4.0-6.7	0.02 / 0.02	<0.02 / 0.02
	August Lady	21.08 / 37.59	210 / 451	6.1 / 5.61	5.6-6.3 / 3.9-6.3	0.02 / 0.01	<0.02 / 0.02
	September Sun	31.75 / 24.38	318 / 368	6.19 / 6.48	5.3-7.0 / 6.0-7.0	0.03 / 0.01	0.02 / 0.04
Location B	Blazeprince	19.56 / 35.56	196 / 425	5.85 / 5.89	4.5-6.5 / 5.5-6.4	0.01 / 0.01	<0.02 / 0.09
	Scarletprince	17.53 / 14.22	174 / 127	6.34 / 6.31	5.5-6.9 / 5.8-7.0	0.02 / 0.02	<0.02 / 0.02
	Redskin	27.43 / 20.57	273 / 248	5.76 / 5.37	4.6-6.6 / 4.7-5.9	0.02 / 0.02	<0.02 / <0.02
	O'Henry	25.15 / 34.04	250 / 375	5.3 / 5.72	4.2-6.2 / 5.1-6.2	0.02 / 0.01	<0.02 / <0.02
	August Lady	21.84 / 24.89	218 / 298	6.4 / 6.55	5.1-7.3 / 6.0-6.7	0.02 / 0.01	<0.02 / 0.03
	September Sun	24.13 / 20.32	241 / 222	5.18 / 5.42	4.1-6.1 / 4.2-6.4	0.01 / 0.01	0.07 / 0.03

^a Minimum and maximum value recorded for cultivar in respective location and experimental year.

^b Numbers separated by '/' indicate values from experimental years 2017 (left) and 2018 (right).

or mixtures of 700 µg/ml NaCl and pH 3 or 10 produced streaking symptoms (Table 3). ClO₂ at 500 µg/ml generated streaking symptoms on ripening fruit (Table 3). Susceptibility to streaking was dependent on fruit maturity and cultivar. Among fruit that was collected 7 days prior to commercial harvest, 'Juneblade', 'Blazeprince', 'Redglobe', 'September Sun', and 'Julyprince' were most susceptible. 'Juneblade' was significantly more susceptible than 'O'Henry', 'Redskin', and 'August Lady' (Figs. 2 and 3). Among fruit harvested 2 weeks before harvest, 'Gloria' was significantly more susceptible than 'September Sun' and 'Scarletprince' (Fig. 4). Ozone at 0.3 µg/ml did not produce symptoms on hanging, treated fruit 1 or 2 weeks prior to commercial harvest (data not shown).

Discussion

Monitoring of streaking in 6 cultivars over two consecutive growing seasons suggested that peach skin streaking is an infrequent, non-cultivar-specific, and localized phenomenon. In one year, streaking appeared in one cultivar of a specific location, and in another, it showed up at a different location and cultivar on the same farm. Likewise, streaking appeared in the same year in one cultivar but not in another nearby. This impeded predictability considerably; however, this also indicated that the occurrence of streaking does not predict continuation of the problem that same year in other cultivars or in the same cultivar the next year. However, streaking did cause significant damage. We recorded incidences of up to 64%. While streaked peaches may be acceptable for local markets, such fruit will experience significant downgrades at the retail level. At best they may qualify for U.S. Grade No. 2, the lowest of four USDA Peach Grades and Standards (USDA Agricultural Marketing Service 2004). Due to the nature of symptom development close to commercial harvest, streaking often goes unnoticed during the production season until harvest.

Our data suggested that the distribution of streaking in single tree canopies appeared to be influenced by the amount of rainfall

associated with the streaking incidence. During heavy rainfall (i.e., more than 25 mm per day), it is more likely that the entire canopy will be wetted evenly, resulting in similar streaking incidence among canopy positions. For light rain events, however, it is reasonable to assume that fruit at the top and sides of the canopy are wetted predominantly, which may lead to localized incidence within single tree canopies. However, more data are needed to conclusively determine the true nature of the relationship between rainfall and streaking occurrence in single tree canopies. There are also alternative explanations that may be considered. The susceptibility to streaking

Fig. 2. Streaking incidence on fruit picked one week prior to commercial harvest and treated with 500 µg/ml chlorine dioxide (ClO₂) solution. LSD test (alpha = 0.05), error bars represent ± 11 SE. Different letters represent significantly different responses between cultivars.

Table 2. Electrical conductivity (EC), oxidation-reduction potential (ORP), and ozone (O₃) content mean values of rainwater collected in 2018 from 12 experimental blocks of a commercial farm in South Carolina

Commercial farm	Cultivar	EC (µS/cm)	EC range	ORP (mV)	ORP range	O ₃ (µg/ml)	O ₃ range
Location A	Blazeprince	11	0-56	197	129-252	<0.02	<0.02
	Scarletprince	69	0-1,505	206	149-263	0.06	<0.02-0.37
	Redskin	8	0-72	242	151-302	0.04	<0.02-0.30
	O'Henry	24	0-214	186	129-279	0.05	<0.02-0.29
	August Lady	18	0-173	202	148-273	<0.02	<0.02
	Sept. Sun	34	0-188	174	127-225	0.02	<0.02-0.13
Location B	Blazeprince	4	0-42	158	98-227	0.05	<0.02-0.31
	Scarletprince	15	0-71	154	87-203	0.05	<0.02-0.27
	Redskin	11	0-66	218	143-269	0.06	<0.02-0.31
	O'Henry	0	0	177	90-231	<0.02	<0.02-0.35
	August Lady	11	0-62	167	101-208	<0.02	<0.02
	Sept. Sun	9	0-62	223	151-255	<0.02	<0.02

Table 3. Streaking symptoms induced on detached peach fruit by experimental dose

Rainwater attributes	Detected range	Experimental dose	Streaking symptoms
pH	3.03 to 7.4	H ₂ SO ₄ ; pH3	No
		NaOH; pH10	No
Electrical conductivity (EC)	0 to 1,505 µS/cm	NaCl 700 µg/ml; 1,500 µS/cm	No
		NaCl 1,500 µg/ml; 3,000 µS/cm	No
Oxidation reduction potential (ORP)	90 to 302 mV	N/A ^a	N/A
Chlorine (Cl ₂)	<0.01 µg/ml	NaClO >100 µg/ml ^b	Yes
Chlorine dioxide (ClO ₂)	<0.02 µg/ml	ClO ₂ >100 µg/ml ^b	Yes
		ClO ₂ 500 µg/ml + NaCl 1,500 µg/ml	Yes
Ozone (O ₃)	<0.02-0.37 µg/ml	O ₃ >0.3 µg/ml	No

^a N/A = not applicable. There was no treatment that specifically tested the influence of ORP on streaking development.

^b Based on previous data published by Hu et al. 2017.

increases as fruit matures and generates more anthocyanins close to harvest (Hu et al. 2017). Photosynthetic photon flux (PPF) is greater in the upper canopy compared with the lower canopy and may lead to differences in pigment formation (Bible and Singha 1993). Hence, differences in streaking incidence with regard to canopy position may also be explained by differing ripening stages of peach fruit within single tree canopies. Lastly, pruning can impose changes on microclimates of fruit tree canopies by altering relative humidity and evaporative potential (Cooley et al. 1997). Such changes could affect exposure of the peach skin to pollutants in rainwater. Therefore, differences in canopy microclimates as a result of pruning may affect distribution of streaking within single tree canopies. However, all trees used in our experiments were open center, and pruning had been conducted to the same standards and by the same pruning crew at the commercial farm and MFRC.

The quality of rainwater varied depending on location, time, and amount of precipitation; however, none of the attributes could be associated with streaking development. Although samples were collected at regular intervals, we acknowledge the potential impact of light and temperature on water chemistry between rain events and sample collection. Rainwater attributes examined in this study included pH value extremes pH 3 and 10, as well as EC value extremes 1,500 and 3,000 $\mu\text{S}/\text{cm}$. Neither of those extremes caused streaking by themselves in our detached fruit tests. Streaking symptoms were produced recently using Cl_2 or ClO_2 solutions with concentrations greater than 100 $\mu\text{g}/\text{ml}$ (Hu et al. 2017). However, levels of Cl_2 or ClO_2 in rainwater were significantly lower than concentrations used to induce streaking symptoms on detached fruit in the laboratory. In 2017, streaking was observed on 'Scarletprince' (LocA) at the commercial farm. This experimental block received 25 mm precipitation in the week prior to symptom development. Rainwater analysis revealed a pH of 6, chlorine content of 0.02 $\mu\text{g}/\text{ml}$ while chlorine dioxide was under the detection limit of 0.02 $\mu\text{g}/\text{ml}$. These findings were not significantly different from rainwater collected from unaffected experimental blocks. It is still possible, however, that combinations of these attribute extremes in rainwater have the ability to damage peach skin. In one instance, we were lucky to have directly associated the occurrence of streaking on 'Carored' (2018; MFRC) after a 50-mm rainfall on May 16 and to have collected sufficient rainwater for follow-up experiments. The rainwater was stored at

4°C for 7 days before it was used for experiments. The stored water produced streaking symptoms on detached 'Rubyprince' fruit (pictures not shown). To the best of our knowledge, this batch of rainwater was free of pesticide residues and had never touched peach tree tissue. Unfortunately, the remaining sample volume did not allow for follow-up studies. This finding combined with our inability to reproduce symptoms with concentrated leaf rinsate further strengthens our hypothesis that rainwater alone can induce streaking.

Detached peach fruit was susceptible to streaking 2 weeks and 1 week prior to harvest, and we noticed differential responses depending on cultivar. Earlier reports confirmed that fruit skin susceptibility to streaking increases as ripening progresses, with fruit 1 week away from harvest being the most susceptible (Hu et al. 2017). In this study, we show that at the same maturity stage there are cultivar differences as well. This may explain anecdotal observations from peach growers who noted that streaking occurred on one

Fig. 4. Streaking incidence on fruit picked 2 weeks prior to commercial harvest and treated with 500 $\mu\text{g}/\text{ml}$ chlorine dioxide (ClO_2) solution. LSD test ($\alpha = 0.05$), error bars represent ± 13 SE. Different letters represent significantly different responses between cultivars.

Fig. 3. Streaking on detached fruit generated using chlorine dioxide (ClO_2) at 500 $\mu\text{g}/\text{ml}$ on cv. Juneblade (left) and cv. August Lady (right). The point of drip treatment is indicated with an arrow, but symptoms on cv. August Lady were evident at lower frequencies.

cultivar but adjacent cultivars of a similar ripening stage may be affected to a lesser extent or not be affected at all (M. Shannon, *personal communication*).

In conclusion, streaking may develop only when multiple factors coincide, including the presence of a susceptible cultivar, susceptible fruit of the susceptible cultivar at the time of rainfall, and rainwater containing one or more streaking-causing agents. The concentration of the streaking agent in rainwater is likely dependent on the amount of rainfall. Our monitoring efforts revealed very different precipitation totals in locations that were less than 2 km apart. For example, one field received 38 mm of rainfall, while another nearby field received 76 mm that same day (data not shown). Such differences in precipitation would greatly influence the concentration of the streaking agent in rainwater, assuming that little precipitation concentrates atmospheric pollutants more than larger precipitation.

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