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Assessing Preharvest Field Temperature and At-harvest Fruit Quality for Prediction of Soft Scald Risk of 'Honeycrisp' Apple Fruit during Cold Storage

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***Abstract*. 'Honeycrisp' apple is susceptible to the postharvest chilling disorder soft scald that renders fruit unmarketable. Reducing or preventing this disorder is an important component of 'Honeycrisp' postharvest management. In commercial settings, advanced fruit maturity and orchard history contribute to an estimation of soft scald susceptibility, but additional at-harvest information indicative of soft scald risk would enable better management decisions. In this study, we obtained fruit from commercial orchards for 3 successive years, and assessed field growing degree days (GDD), field chilling hours (CH), and fruit quality metrics at harvest, followed by soft scald incidence assessment at 12 weeks of cold storage. The analyses indicated starch index, soluble solids content (SSC), internal ethylene concentration, titratable acidity (TA), peel background color, firmness, GDD, or CH do not reliably indicate fruit susceptibility to soft scald. However, SSC and TA were elevated in fruit that later developed soft scald, and a higher number of GDD also sometimes preceded soft scald, which is consistent with advanced fruit maturity that can enhance soft scald risk. Overall, results suggest that other tools may be required to accurately predict postharvest soft scald on a quality control laboratory scale. The statistical analyses applied to the present study would have utility for assessing other soft scald prediction tools or markers.**

'Honeycrisp' is a popular apple cultivar, savored for its unique crispness and sweet taste. There is economic incentive to lengthen the period of fruit availability through postharvest storage, but several physiological disorders plague storage success, including soft scald (El-Shiekh et al., 2002; Tong et al., 2003). Soft scald is characterized by sharply demarcated irregular large brown lesions on fruit peel where tissue is slightly sunken and less firm (soft) to the touch (Plagge and Maney, 1924). Later in storage, pathogens can infest the affected tissue. Soft scald is often found concomitant with soggy breakdown, a fruit cortex, or flesh, disorder in which regions of brown water–soaked tissue have similarly sharply defined edges (Barker, 1930; DeEll and Ehsani-Moghaddam, 2010; Snowdon, 1990; Watkins et al., 2004).

The variation of susceptibility to soft scald among orchards has been partially attributed to preharvest factors, including climatic conditions during fruit growth (Lachapelle et al., 2013; Moran et al., 2009), orchard location and fruit mineral element concentration (Tong et al., 2003), preharvest plant growth regulators treatments, such as 1-methylcyclopropene (DeEll and Ehsani-Moghaddam, 2010), and fruit maturity at the time of harvest (Tong et al., 2003; Watkins et al., 2003). The information regarding these treatments or field conditions is neither controlled by nor necessarily available to storage and packing sheds when fruit are received. For this reason, quality and maturity metrics may be useful to assess the physiological condition of fruit when it arrives at storage sheds and are used to make storage decisions. These assessments include peel background color, flesh firmness, SSC, starch index (SI), and TA. In Washington, weather stations situated at numerous locations across the state (Washington State University AgWeatherNet <www.weather.wsu.edu>) could also allow assessment of climactic factors, including GDD and CH.

Quality and maturity metrics vary greatly at the time of harvest. Although these quality and maturity measurements tend to follow a predictable progression in storage [i.e., the gradual decrease in fruit firmness and TA (Jan et al., 2012)], the ratio of one metric to another is not always consistent among fruit harvests (Watkins et al., 2005). Quality and maturity measurements also indicate important physiological processes in the fruit, including maturity, ripening, and senescence, which have demonstrated relationships with soft scald/soggy breakdown (Watkins et al., 2003). Previous work has further demonstrated that preharvest climactic conditions can impact 'Honeycrisp' postharvest disorders, such as low temperature affecting diffuse flesh browning (Tong et al., 2016) and precipitation affecting soft scald (Moran et al., 2009). It is not clear whether quality and maturity metrics also consistently reflect aspects of underlying fruit physiology that increases susceptibility to soft scald and soggy breakdown, although soluble solids have been documented to be negatively correlated with soft scald incidence (Tong et al., 2016).

The goal of this study was to assess readily accessible field temperature data and easily measurable fruit quality/maturity metrics as tools for making storage decisions to reduce the incidence of soft scald in 'Honeycrisp' apples during storage. We hypothesized that results would indicate the potential for quality and maturity measurements to be used as metrics to predict the incidence of storage disorders soft scald at harvest or during storage.

Materials and Methods

Harvest 2011. 'Honeycrisp' apples [*Malus sylvestris* (L.) Mill var. *domestica* (Borkh.) Mansf.] were obtained from growers/cooperators at 15 orchards distributed among the Lake Chelan/Brewster, Columbia Basin, and Yakima Valley growing regions in Washington State and the Hood River growing region of Oregon State between 2 Sept. and 21 Oct. 2011 (locations indicated in Fig. 1A and harvest dates listed in Table 1). No preharvest treatments were applied, with the exception of an ethylene biosynthesis inhibitor (Retain; Valent BioScience Corporation, Libertyville, IL) to one orchard (Orchard M). To determine the effects of harvest-timing on postharvest soft scald and soggy breakdown, fruit from one site was harvested on three different dates, to represent an early, midseason, and late

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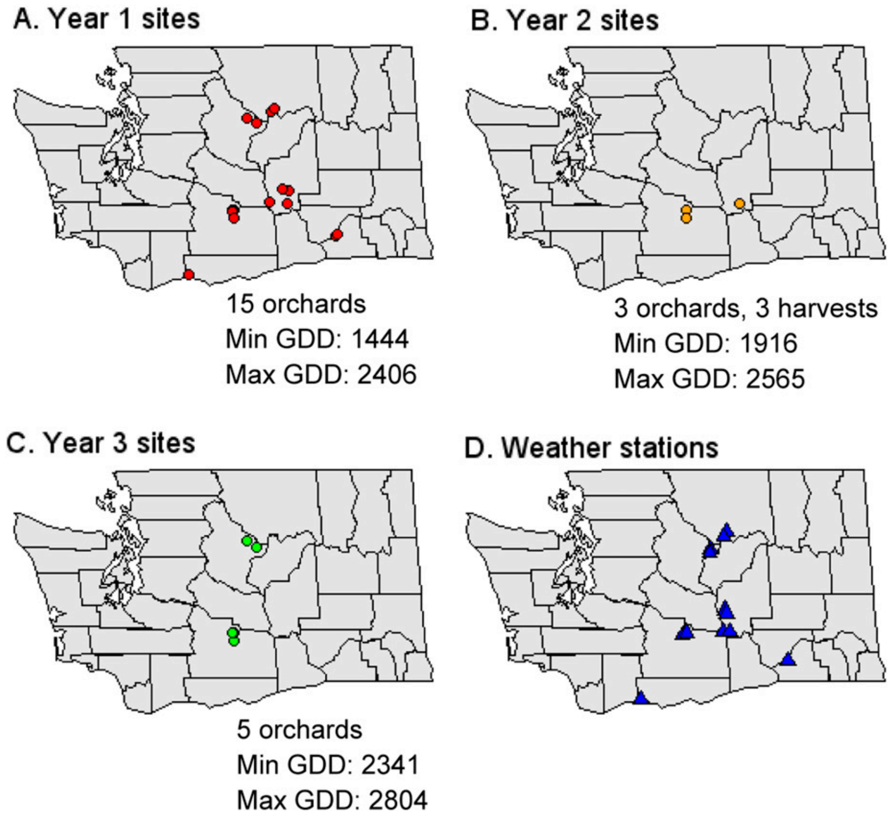

Fig. 1. 'Honeycrisp' fruit was obtained from 15 orchards in Washington State in 2011 (one orchard with three successive harvests) (**A**), three orchards with three successive harvests each in 2012 (**B**), and four orchards in 2013 (one with three successive harvests) (**C**). Growing degree days (GDDs) and chilling hours for each orchard was obtained from the Washington State University AgWeatherNet station closest to each orchard (**D**).

harvest (Orchard A). In 2011 as well as 2012 and 2013, quality and maturity measurements were performed on the day of harvest (section 2.4). Fruit was stored at 1 °C with no atmospheric modifications, and after 12 weeks, the incidence of soft scald and soggy breakdown was assessed.

Harvest 2012. 'Honeycrisp' apples were obtained from growers/cooperators at three sites in the Columbia Basin and Yakima Valley region of Washington State between 29 Aug. and 3 Oct. 2012 (locations indicated in Fig. 1B and harvest dates listed in Table 1).

Harvest 2013. 'Honeycrisp' apples were obtained from growers/cooperators at five sites in the Lake Chelan and Yakima Valley region of Washington State between 11 Sept. and 26 Sept. 2013 (locations indicated in Fig. 1C and harvest dates listed in Table 1). The ethylene action inhibitor 1-methylcyclopropene (Harvista; AgroFresh Inc., Spring House, PA) had been applied to orchards A and M before harvest by the grower according to label instructions.

Field temperature data, quality metrics, and soft scald disorder assessment. GDDs (base 10 °C) and CHs (base 4.4 and 10 °C) for each orchard were estimated using publicly available data obtained from the closest weather station via the Washington State University AgWeatherNet system (http://weather.wsu.edu/awn.php). Locations of weather stations used are indicated in Fig. 1D and corresponding annual GDD and CH are listed in Table 1.

One tray (16 fruit) was subjected to standard quality and maturity assessment at harvest for each orchard each year. Quality and maturity assessments recorded fruit mass, peel background color, peel chroma (C^*), and hue angle ($h°$), flesh firmness, internal ethylene concentration (IEC), SSC, SI, and TA.

Peel background color was subjectively rated using a color wheel as a guide (U.S. Department of Agriculture, Standard Ground Color Chart for Apples and Pears in Western States). The same person rated all the fruit for the entire experiment.

Color was recorded as CIE $L^*a^*b^*$ (McGuire, 1992) with a chromameter (Minolta CR-300 Chroma meter; Konica Minolta, Tokyo, Japan). Chroma (C^*) was calculated as $\sqrt{(a^{*2} + b^{*2})}$ from intensity of red or green (a*) and intensity of yellow or blue (b*). Hue angle ($h°$) was calculated as arctangent (b*/a*) (McGuire, 1992).

Firmness was analyzed with a Mohr Digi-Test 1.25 penetrometer (Mohr & Associates, Richland, WA) equipped with an 11-mm tip on one pared surface of each fruit. The parameters M1, Cn, C0, and E2 were collected (Evans et al., 2010; Mohr and Mohr, 2011). The maximum external fruit pressure (N) is termed M1, and indicates the firmness of the fruit from the peel boundary to a depth of 0.813 cm. E2 measures the pressure (N) at the boundary of the core (core firmness). Crispness (Cn) is a unitless measurement of the energy released during a pressure test, analogous to the energy released when biting into a fruit (Mohr and Mohr, 2011). Creep deformation (C0) measures the distance of fruit collapse under a 44.5 N creep force for 0.5 s from 0.813 cm. Low-quality fruit will have a higher creep factor than good-quality fruit.

Starch hydrolysis was visually assessed on a full-width tissue slice cut from the fruit equator using a 1–6 scale (Hanrahan, 2012) after staining with a 0.024-M iodide–potassium iodide solution. The same person visually assessed starch throughout the experiment.

Fresh juice prepared from sectioned whole apples passed through a Champion juicer (Plastaket Mfg., Lodi, CA) was used to measure SSC using a handheld refractometer (ATAGO, Tokyo, Japan), and TA by titrating 10-mL juice with 0.1-M KOH to pH 8.2 using an autotitrator (TIM850; Radiometer Analytical, Copenhagen, Denmark).

IEC was measured by piercing the calyx end of the fruit with a wide-bore needle equipped with a septum. A 1-mL plastic syringe with a 1-inch needle (BD, Franklin Lakes, NJ) was used to pierce the septum and slowly draw up 1 mL of gas sample from the fruit cavity; 0.5 mL of the gas was injected into a 5880A GC-FID (Hewlett-Packard, Avondale, PA) equipped with a 50-cm, 0.32-cm-i.d. glass column packed with 80- to 100-mesh Porapak Q (Supelco, Bellefonte, PA). The 5880 GC-FID was calibrated each day with 0.5-mL gas containing 9.01 ppm authentic standard (Scotty Analyzed Gases, Bellefonte, PA). The temperature of injector, oven, and detector was 100, 130, and 200 °C, respectively. Gas flows for air, N_2, and H_2 were 300, 30, and 30 $mL \cdot min^{-1}$, respectively.

Three trays of fruit (48 fruit) from each orchard were assessed for soft scald incidence after 12 weeks of storage at 1 °C. Soft scald was recorded as present (1) or absent (0). For subsequent analyses, categorization of at-harvest quality metrics was applied according to orchard: at-harvest quality metrics from orchards containing greater than 5% fruit with symptoms of soft scald at 12 weeks were categorized as "high-risk" for soft scald, whereas orchards with incidence of soft scald below 5% were categorized as "low-risk."

Data analysis. Classical univariate receiver operatorting characteristic (ROC) curves and analyses were performed via ROCCET.ca (Xia et al., 2012). ROC curves can be used to evaluate data for the presence, sensitivity, and specificity of biomarkers that indicate or predict the presence or absence of a qualitative characteristic, for example, disease state (Xia et al., 2012). In this study, quality and maturity measurements were classified as potential biomarkers to predict the outcome of soft scald (positive/negative) or the outcome of soft scald–free fruit

Table 1. Orchard and field temperature data and quality metrics summary for all 3 years of the study.

Orchard[z]	WSU AgWeatherNet weather station	Yr	Harvest date	Growing degree days (base 10 °C)	Chilling hours (base 4.4 °C)	Chilling hours (base 10 °C)	Wt (g)	Firmness (M1) (N)	Soluble solids (°Brix)	Background color	Starch (1–6)	Titratable acidity (%)	IEC ($\mu L \cdot L^{-1}$)
A_H1	Gleed	1	2 Sept. 2011	1444	0	11	236.5	71.6	12.2	–	1.2	56	0.33
B	Desert Aire	1	11 Sept. 2011	2596	0	0	296.9	62.3	13.7	3.0	5.5	43	14.19
C	Mattawa	1	15 Sept. 2011	2368	0	3	268.4	56.5	13.3	3.6	5.3	43	16.62
A_H2	Gleed	1	19 Sept. 2011	1708	0	36	325.0	59.2	13.7	3.2	5.1	54	14.65
D	Royal City West	1	20 Sept. 2011	2215	0	1	263.4	57.8	13.0	2.7	4.4	54	5.57
E	Crane	1	21 Sept. 2011	2328	0	0	266.1	68.9	13.5	2.8	4.0	57	1.76
G	Cowiche	1	26 Sept. 2011	2051	0	62	236.0	63.2	13.8	2.7	4.6	56	3.67
F	FishHook	1	26 Sept. 2011	2283	0	46	300.8	60.1	12.8	3.6	5.1	51	5.46
I	Brewster Flat	1	28 Sept. 2011	1963	15	179	260.1	75.2	15.1	4.1	5.0	54	2.53
H	Brewster Flat	1	28 Sept. 2011	1963	15	179	267.2	66.3	13.6	4.0	5.8	43	1.32
J	FishHook	1	29 Sept. 2011	2306	3	60	237.5	59.6	14.0	3.9	5.8	49	0.34
K	Frenchmen Hills	1	3 Oct. 2011	2036	1	99	284.0	55.2	13.0	3.5	5.6	35	2.11
A_H3	Gleed	1	5 Oct. 2011	1829	0	138	305.0	58.7	13.8	3.9	5.8	46	2.34
L	Chelan South	1	6 Oct. 2011	2406	0	35	256.4	60.9	12.2	3.8	5.2	43	3.54
M	Cowiche	1	7 Oct. 2011	2104	5	147	266.7	61.8	13.5	3.1	5.2	47	4.19
N	Underwood	1	18 Oct. 2011	1686	1	149	191.4	61.4	11.7	2.2	5.7	41	3.84
O	Cowiche	1	20 Oct. 2011	2120	24	311	276.3	57.4	12.6	2.7	6.0	46	3.37
P	Boyd District	1	21 Oct. 2011	1917	32	367	222.9	64.5	11.6	3.6	6.0	39	0.92
C_H1	Mattawa	2	29 Aug. 2012	2360	0	1	253.8	64.5	11.0	2.2	2.4	59	3.27
C_H2	Mattawa	2	3 Sept. 2012	2445	0	1	299.4	65.4	12.3	2.9	3.8	62	1.07
C_H3	Mattawa	2	10 Sept. 2012	2565	0	2	269.6	60.1	11.5	3.2	4.3	50	2.88
G_H1	Cowiche	2	10 Sept. 2012	2135	0	23	248.1	63.6	12.1	3.2	3.8	56	1.00
G_H2	Cowiche	2	13 Sept. 2012	2154	2	54	230.0	72.5	13.4	4.0	3.8	70	1.56
G_H3	Cowiche	2	26 Sept. 2012	2355	2	73	208.7	61.4	12.9	3.7	5.7	52	0.78
A_H1	Gleed	2	13 Sept. 2012	1916	0	50	279.3	64.5	13.4	3.3	4.3	54	2.84
A_H2	Gleed	2	25 Sept. 2012	2086	0	63	217.1	56.5	13.6	3.0	4.9	56	1.34
A_H3	Gleed	2	3 Oct. 2012	2158	6	106	201.3	57.8	13.1	3.3	5.8	38	0.53
K	Chelan South	2	11 Sept. 2013	2804	0	0	245.0	60.1	12.5	3.2	4.8	51	10.01
G_H1	Cowiche	3	12 Sept. 2013	2524	0	2	222.1	64.5	12.9	2.8	5.0	51	1.45
A	Gleed	3	17 Sept. 2013	2341	0	0	255.4	58.7	14.0	3.6	5.1	48	4.04
G_H2	Cowiche	3	18 Sept. 2013	2638	0	9	253.1	56.9	12.3	3.4	4.9	48	2.81
L	Cowiche	3	19 Sept. 2013	2645	0	18	229.5	58.7	12.4	3.3	4.4	50	3.88
P	Boyd District	3	26 Sept. 2013	2414	0	67	241.6	70.3	13.9	3.6	4.4	65	0.40

[z] Orchard letter code followed by H1, H2, or H3 indicates the first, second and third harvest. Fruit from all orchards were obtained at commercial harvest.

IEC = internal ethylene concentration; WSU = Washington State University.

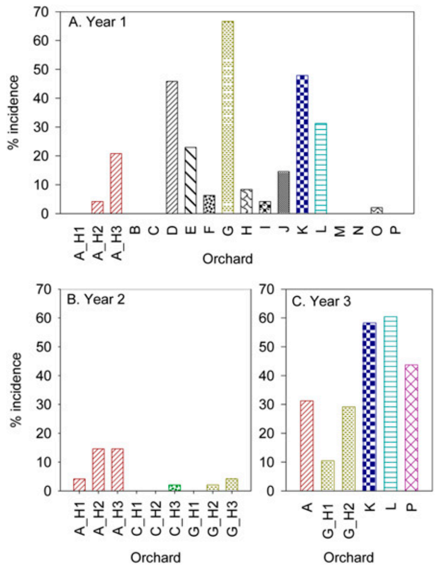

Fig. 2. Soft scald percent incidence after 12 weeks of storage in the Fall of 2011 (**A**), 2012 (**B**), and 2013 (**C**).

(positive/negative), if a high value in the measurement was associated with soft scald risk or if a high value in the quality/maturity measurement was associated with healthy fruit, respectively.

Orchards and their respective at-harvest quality/maturity data were categorized post facto as either ‘‘high-risk’’ or ‘‘low-risk,’’ depending on the soft scald incidence outcome at 12 weeks. The area under the ROC curve for each quality parameter was established within a 95% confidence interval calculated by using 500 bootstrappings. The optimal threshold for each parameter was established at the intersection of the highest true-positive and true-negative rate.

Results and Discussion

Each orchard, picking sequence and year provided variable incidences for soft scald (Fig. 2). In 2012 (Fig. 2B), a malfunctioning cooling element resulted in fluctuating temperatures higher than the intended 1 °C (between 2 and 4 °C), which likely reduced the overall incidence of soft scald and soggy breakdown, because higher temperature storage reduces soft scald/soggy breakdown incidence (Watkins et al., 2004).

ROC analysis indicated significant differences (*t* test, $P < 0.05$) in background color, core pressure (E2), creep deformation (C0), CH base 4.4 °C and CH base 10 °C, GDD base 10 °C, IEC, SSC, and SI among the orchards that had soft scald at 12 weeks in storage compared with orchards that remained soft scald–free (Fig. 3). However, ROC analysis enables an enhanced interpretation beyond differences of within quality/maturity metrics at harvest between resistant and susceptible orchards. The threshold value for each quality parameter, combined with the true/false-positive, true/false-negative rate (Table 2), and area under the curve (Table 3) allows for assessment of the utility of any of these quality metrics as an indicator for soft scald risk at the time of harvest. For example, when higher values of a fruit quality/maturity measurement are associated with a higher risk for soft scald, true positives occur when the quality parameter level is above the specified threshold, and the orchard

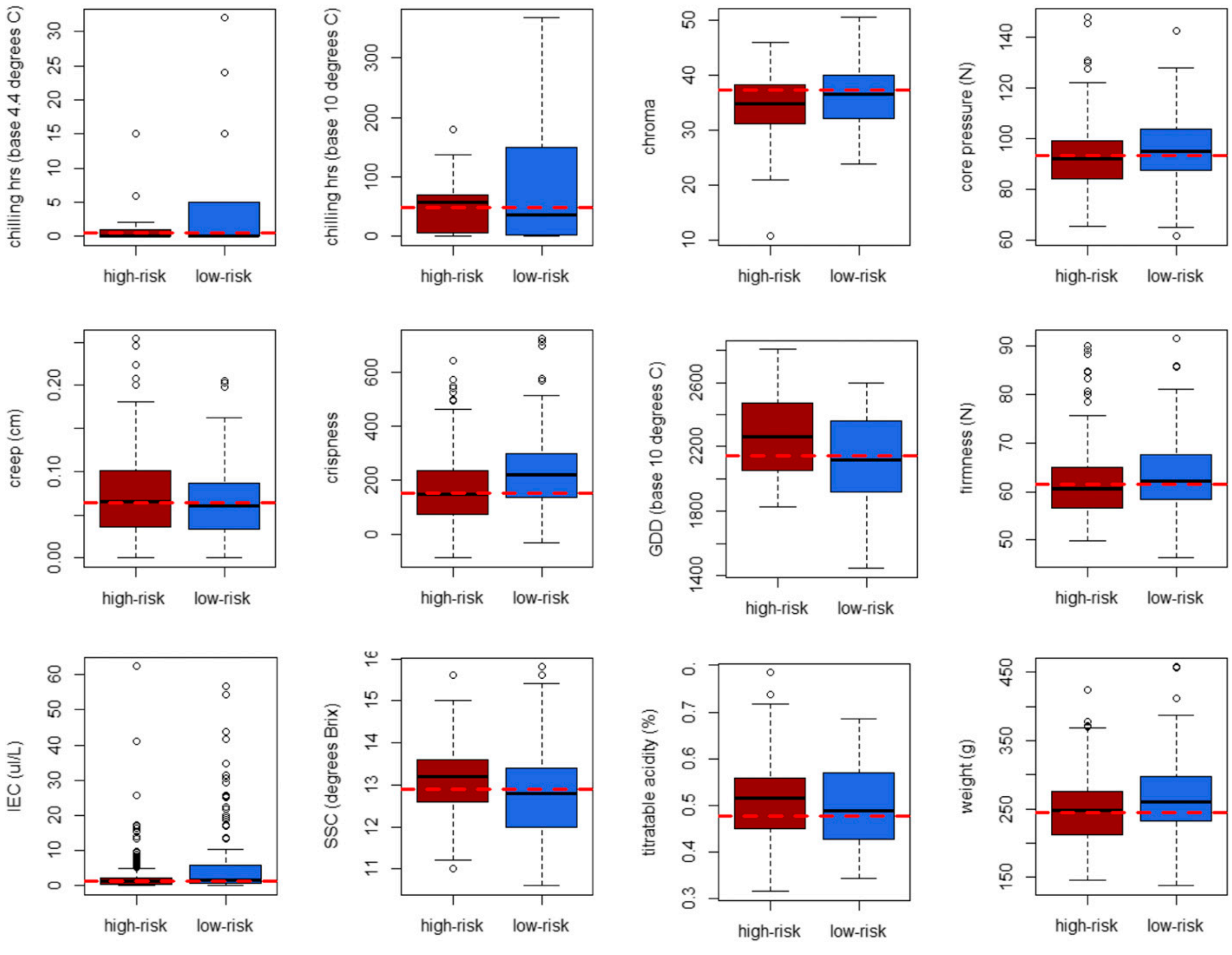

Fig. 3. Boxplots indicate high-risk and low-risk values for field temperature data and at-harvest quality measures that were evaluated for their ability to predict incidence of soft scald at 12 weeks of storage. The dashed line indicates the threshold value for either low- or high-risk prediction. GDD = growing degree day; IEC = internal ethylene concentration; SSC = soluble solids concentration.

Table 2. Receiver operating characteristic (ROC) analysis indicated the sensitivity and specificity of field temperature data and at-harvest quality metric thresholds for indicating soft scald risk. This table defines true positives (sensitivity), true negatives (specificity), false positives, and false negatives in the context of ROC analysis results.

	Risk indicated by theoretical sample comparison with threshold value	
True outcomes	High soft scald risk	Low soft scald risk
More than 5% of fruit had soft scald at 12 weeks after storage inception	True positive (TP) “Sensitivity” = TP/(TP+FN)	False negative (FN)
	Soft scald risk indicated by test and soft scald was present.	Low soft scald risk indicated by test but soft scald incidence was present.
Less than 5% of soft scald at 12 weeks after storage inception	False positive (FP)	True negative (TN) “Specificity” = TN(FP+TN)
	High soft scald risk indicated by test when fruit had low incidence of soft scald.	Low soft scald risk indicated by test and incidence of soft scald was low.

Table 3. Field temperature data and at-harvest quality measures were evaluated for their ability to predict incidence of soft scald at 12 weeks of storage.

Measurement	P[z]	Threshold value[y]	True-negative rate (sensitivity)[x]	True-positive rate (specificity)[x]	AUC[w]
Chilling h base 4.4 °C	<0.00001	0.5	0.61	0.30	0.572
Chilling h base 10 °C	<0.00001	**48**	0.60	0.62	0.474
Chroma	0.00045	37.3	0.46	0.68	0.579
Core pressure (N)	0.00076	93	0.56	0.55	0.585
Color	0.00016	**3.5**	0.49	0.68	0.624
Crispness	<0.00001	152	0.66	0.63	0.644
Creep (cm)	0.00159	**0.065**	0.51	0.57	0.554
Firmness (N)	0.00895	61.5	0.55	0.56	0.577
Growing degree days base 10 °C	<0.00001	**2140**	0.65	0.61	0.640
Hue	0.1571	101	0.58	0.44	0.527
Internal ethylene (µL/L)	0.00017	**1.43**	0.60	0.45	0.523
Soluble solids content (°Brix)	<0.00001	**12.9**	0.68	0.57	0.640
Starch (1–6)	0.01773	**4.9**	0.60	0.57	0.650
Titratable acidity (% malic acid)	0.1441	**0.477**	0.68	0.47	0.548
Weight (g)	0.03447	245	0.63	0.49	0.586

[z] P values indicate significance in *t* test of comparison of field temperature or at-harvest quality data classified post hoc as low risk or high risk for soft scald, depending on 12 weeks of storage outcomes.

[y] Threshold value establishes the cutoff value for low-risk and high-risk categories. Values in “threshold value” that are gray indicate fruit quality/maturity measurements are expected to be higher for low-risk fruit; values in bold indicate that fruit quality/maturity measurements are expected to be higher in high-risk fruit.

[x] True-positive and true-negative rate indicate the sensitivity and specificity of low or high soft scald risk predicted rate at the indicated threshold value.

[w] Area under the curve (AUC) is the probability that a randomly chosen positive instance will rank higher than negative one; there is little utility for parameters with AUCs less than 0.7.

ultimately had soft scald incidence in storage; true negatives occur when the quality parameter level is below the specified threshold and fruit from that the orchard remained disorder-free. Most quality parameters proved to be inconsistent predictors of disorder incidence, based on evaluation of these results, despite significant differences in the *t* test. In the present results, higher core pressure (above 93 N), higher crispness (above 152), and higher firmness (61.5 N) were found in fruit that did not develop soft scald. Conversely, higher IEC (above 1.43 $\mu L\cdot L^{-1}$), higher SSC (above 12.9 °Brix), and TA (above 0.47% malic acid) were relatively higher in fruit that later developed soft scald. Per evaluation of ROC output, these parameters have little utility for soft scald prediction: all had an area under the curve (AUC) value of less than 0.7; in this case, AUC is an indicator of the predictive value of quality/maturity measurements. Values near 0.5 indicate that for a randomly chosen measurement, the likelihood that the value correctly indicates the sample is at risk for soft scald is $\approx$50%. In addition, not a single parameter had both a true-positive and a true-negative rate greater than 0.70. When higher values of a fruit quality/maturity measurement are associated with higher risk of soft scald, and the true-negative value is low, this means that the test is more prone to false positives: the quality parameter may be above the threshold level, indicating high likelihood of soft scald development, but the disorder never occurs. When the true-positive value is low, false negatives are more likely to occur: the quality parameter may be below the threshold level, indicating that the fruit is at lower risk for developing soft scald, but it does develop the disorder at some point in storage.

Numerous studies have researched the relationship among ‘Honeycrisp’ soft scald and soggy breakdown and a wide range of preharvest and postharvest parameters (DeLong et al., 2004; Moran et al., 2009, 2010; Robinson and Lopez, 2009; Watkins et al., 2005). This study aimed to assess at-harvest temperature data or quality metrics as predictors of soft scald via ROC analyses. The advantage of the parameters used in this study [field temperatures (GDD and CH) and quality metrics (SSC, TA, IEC, firmness, SI, color, and fruit weight)] is that these metrics could be readily available to a storage shed at the time of harvest in Washington State. For weather data, there is an extensive system of weather stations (AgWeatherNet, Washington State University, www.weather.wsu.edu) from which data can be freely downloaded at any location with a device that has an Internet connection. However, even orchards in close vicinity of a weather station may have a unique microclimate based on irrigation method, tree structure and age, or the use of evaporative cooling or netting (Hanrahan, personal communication). The chosen quality metrics could also be readily assessed through in-house quality testing, given the appropriate instruments.

ROC analysis evaluated the potential for use of fruit quality parameters measured at harvest as predictors of soft scald risk. Results indicated that the standard quality parameters are inconsistent predictors of storage outcomes with respect to soft scald. Higher crispness, higher core pressure, higher firmness, and reduced creep deformation were associated with lower likelihood of soft scald. These trends are consistent with less mature fruit, which are generally less susceptible to soft scald (Watkins et al., 2003). In contrast, higher SSC and TA were sometimes associated with higher soft scald risk. Higher SSC is related to increased fruit maturity (Kader, 1999) and later harvests (Jan et al., 2012); more mature fruit and later harvests are more prone to soft scald (Watkins et al., 2003, 2005).

In this study, TA was, on average, higher in fruit that eventually developed soft scald. TA can be influenced by many agronomic factors, including crop load (Robinson and Watkins, 2003), temperature, potassium fertilization (Lobit et al., 2006), and irrigation (Etienne et al., 2013). These same factors can influence disorder susceptibility (Moran et al., 2009; Robinson and Watkins, 2003; Tong et al., 2003), potentially explaining a link between TA and soft scald. To date, however, no physiological role for TA in soft scald development has been demonstrated.

Although current research results were not consistent enough for any single fruit quality parameter to be infallibly used as metric for predicting storage success, especially when using small numbers of fruit, we suggest continued evaluation of both SSC and TA in relation to soft scald disorder outcome.

In conclusion, 3 years of 'Honeycrisp' data in Washington State indicated that freely available weather station data and common fruit quality measurements as assessed at harvest are not reliable indicators for soft scald later in storage. Future work could incorporate a refinement of parameters, such as a larger fruit sample per site (≥100), temperature data taken directly in the orchard, several gradients of CHs (0, 1, 2, 4, 7, and 10 °C), and a more refined SSC (low-medium-high-very high).

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