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Modeling the effect of preharvest weather conditions on the incidence of soft scald in 'Honeycrisp' apples

Maude Lachapelle[a], Gaétan Bourgeois[a,*], Jennifer DeEll[b], Katrine A. Stewart[c], Philippe Séguin[c]

[a] Horticultural Research and Development Center, Agriculture and Agri-Food Canada, 430 Gouin Boulevard, Saint-Jean-sur-Richelieu, Québec, Canada J3B 3E6
[b] Ontario Ministry of Agriculture, Food and Rural Affairs, Box 587, 1283 Blueline Road at Hwy 3, Simcoe, Ontario, Canada N3Y 4N5
[c] McGill University, Department of Plant Science, Macdonald Campus, Raymond Building, 21111 Lakeshore Road, Sainte-Anne-de-Bellevue, Québec, Canada H9X 3V9

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ABSTRACT

'Honeycrisp' apples show a high susceptibility to physiological disorders such as soft scald. The objective of this study was to identify weather parameters during fruit development that influence soft scald development in 'Honeycrisp' apples. Soft scald susceptibility of 'Honeycrisp' has been linked to weather conditions during specific periods of the growing season, referenced by given phenological stages. Using weather data and fruit quality analysis data from three sites in Ontario, two sites in Quebec and one site in Nova Scotia for three seasons (2009–2011) and four additional sites in Ontario from 2002–2006, a model for soft scald incidence (SSI) was built to predict the susceptibility of 'Honeycrisp' apples prior to storage. This model used primarily two weather variables during three sub-periods of fruit development to accumulate a SSI index (%) during the growing season, from full bloom to harvest time. Relatively wet conditions during phenological stages from full bloom until 10 mm diameter (precipitation > 0.5 mm) and from 10 mm until 50% of final caliber (precipitation > 6.0 mm), cool conditions (temperature < 15 °C) from full bloom until 10 mm diameter, and warm conditions (temperature > 20 °C) from 50 to 80% of final size are conditions that resulted in increased soft scald susceptibility for 'Honeycrisp' apples. The SSI model may be used by producers to establish more appropriate marketing and storage strategies depending on levels of susceptibility to soft scald development predicted prior to storage.

1. Introduction

Since its release in 1991, the 'Honeycrisp' apple has gained popularity in the northern regions of the United States and Canada. In spite of good quality attributes, such as firm texture and juiciness, 'Honeycrisp' demonstrates a high susceptibility to physiological disorders, such as soft scald. This disorder is characterized by well-defined brown lesions on the skin of the apple, with damage also into the first hypodermal tissue layers (DeEll, 2009). Multiple factors have been implicated in the development of soft scald, mainly over-maturity at harvest, light crops, large fruit and low temperature during storage (DeEll, 2005). Holding apples at 10–20 °C for up to 7 days before storage at lower temperatures (i.e. 3 °C) is a technique used to delay the incidence of soft scald in long-term storage (Watkins et al., 2004). Fruit quality attributes are the most used indicators for maturity at harvest. In the case of 'Honeycrisp' apples, low soluble solids content at harvest has already been linked to increased soft scald incidence for Ontario (Moran et al., 2009). However, this indicator is specific for one region and has not been highlighted in other cases of soft scald development. Furthermore, variation in such quality attributes and different patterns of quality evolution have been observed in 'Honeycrisp' during the growing season and throughout harvest, making it difficult to relate them to maturity (Watkins et al., 2005; DeEll and Ehsani-Moghaddam, 2010). One common factor between regions of harvest is the impact of weather conditions during the growing season that are frequently associated with this disorder, but to date this has been limited to cool and wet conditions near harvest time (DeEll, 2005; Moran et al., 2009).

The objective of this study was to determine if the occurrence of specific weather parameters at critical times during the growing season is more influential on the susceptibility of 'Honeycrisp' to soft scald than overall weather parameters throughout the growing season. Using weather data throughout the growing season from a range of locations from 2002 to 2006 and 2009 to 2011, specific weather patterns during targeted stages of fruit development were examined for possible association with soft scald incidence in 'Honeycrisp' apples. This project aimed to: (1) identify weather parameters during specific apple fruit phenological phases that influence soft scald incidence on 'Honeycrisp' apples in storage, and (2) conceptualize a dynamic bioclimatic model based on this information to predict the risks of soft scald development

* Corresponding author. Tel.: +1 450 515 2017; fax: +1 450 346 7740.
E-mail address: gaetan.bourgeois@agr.gc.ca (G. Bourgeois).

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prior to storage. Accurate predictions of soft scald incidence during storage could be used by apple producers to establish more appropriate management of fresh fruit loads depending on regional and seasonal susceptibility to this disorder.

2. Materials and methods

2.1. Sites and years of harvest

In 2009–2011, 'Honeycrisp' apples were harvested from three sites in Ontario (Newcastle, Norfolk County and Georgian Bay), one site in Nova Scotia (Kentville) and two sites in Quebec (Franklin and Île d'Orléans). Apples were stored at 3 °C for 3–4 months at the Storage Research Facility in Simcoe (Ontario). Fruit from Ontario and Quebec were transported to the facility on the same day as harvest, while those from Nova Scotia were transported via refrigerated truck at ∼3 °C for 3 days. Two bushels, each containing about 60 apples, were obtained from each site and year. Data were also collected from the Ontario (Norfolk Co.) site in 2002–2006, as well as from four nearby sites (within 20 km). These apples were also stored on the same day as harvest, but were stored at 0.5–1 °C for 4–5 months to potentially induce soft scald.

2.2. Fruit quality analyses

Sub-samples of 10 apples were analyzed for maturity at harvest. Since fruit maturity at harvest is related to the incidence of storage disorders (Watkins et al., 2005), it was important that background color was changing from green to yellow and that the starch index was between 5 and 7, as determined by the Cornell Starch Chart (Blanpied and Silsby, 1992). After 3–4 months in storage, 20 apples per location were evaluated for fruit quality, including incidence of soft scald, while the remaining fruit (∼30 per location) were evaluated only for incidence of soft scald.

Evaluation of fruit quality at harvest and after storage was carried out using the same protocol as in DeEll and Ehsani-Moghaddam (2010). Internal ethylene concentration was determined by extracting a 3 mL gas sample from the core of each apple, using a syringe, and then injecting the sample into a Varian CP-3380 Gas Chromatograph (Varian Canada Inc., Mississauga, ON). Starch index was determined using the Cornell scale. Apples were cut in half at the equator and rated on a scale of 1–8, where 100% starch staining is 1 and 0% is 8. Soluble solids concentration was determined using a digital BRX-242 Refractometer (Atago Co., Ltd., Japan). The apple juice from the 10 apples in the sub-sample was pooled for this measurement. Titratable acidity (expressed as mg equivalents of malic acid per 100 mL of juice) was determined by titrating a 2 mL juice sample, taken from the 10 apples per box, with a 0.1 N NaOH solution to an endpoint of pH 8.1 (as indicated by phenolphthalein). Fruit firmness was evaluated on opposite sides of each apple using the electronic Fruit Texture Analyzer fitted with an 11 mm tip (GÜSS, South Africa), after removing the peel on each side. Soft scald incidence was determined for every apple after storage, by presence or absence of the disorder regardless of severity.

2.3. Monitoring and management of weather data

Weather data were obtained from either the weather stations of the Quebec Apple Network or the *National Climate Data and Information Archive Network* according to their proximity to the orchards (Environment Canada, 2010; Sarrazin, 2006). For the two sites in Quebec, weather stations were located in the orchards. Weather parameters available for analysis include hourly or daily minimum, maximum, and mean temperatures (°C), relative humidity (%), and total precipitation (mm). For the three sites in Ontario, weather stations selected were Delhi (Norfolk Co.), Cobourg (Newcastle) and Collingwood (Georgian Bay). In Nova Scotia, a weather station situated directly in Kentville was selected.

2.4. Data management and statistical analyses

The weather data from all weather stations were divided according to Moran et al. (2009) in sub-periods of days from full bloom until harvest time, with additional levels of precipitation and temperature. For each sub-period of fruit development and each location, calculations were made to determine the number of hours when relative humidity > 85%, the number of hours when mean air temperature < 5–30 °C by steps of 5 °C, the number of days with precipitation > 0.5–2.5 mm by steps of 0.5 mm, >5.0 and >6.0 mm, the average maximum air temperature and the accumulated precipitation per year.

The GLM procedure using least squares method was used to verify the inter-annual and inter-regional variations in the weather conditions and temporal statistics, using the ARIMA procedure, to detect trends in daily weather data. Principal component analysis (PCA) using the XLSTAT software detected correlations between weather parameters, in terms of days from full bloom, and soft scald incidence. The REG procedure and the STEPWISE selection were used to analyze the effect of all fruit quality attributes and weather conditions on soft scald incidence. These tests were performed in SAS 9.2 software (SAS Institute, Inc., Cary, NC).

2.5. Mathematical modeling process

2.5.1. Modeling of the phenological development

A phenological prediction model of 'Honeycrisp' apples was prepared using weekly samples taken from 10 'Honeycrisp' apple trees on the experimental farm of Agriculture and Agri-Food Canada, in Frelighsburg (QC), during the 2010 and 2011 growing seasons and weather data from an automatic station located in the orchard. The 'McIntosh' phenology model already implemented in the CIPRA software (Bourgeois et al., 2008) was used as a reference point. The model has a base temperature of 5 °C, optimum temperatures between 22 and 25 °C and a maximum temperature of 36 °C. The model is divided into five phases of development: emergence, foliar development, transition between vegetative and reproductive growth, and two phases of reproductive development (Bourgeois et al., 2013).

Since only full bloom and harvest dates were known for each site and year of data in this study, it was important to be able to link the number of days from full bloom (DFB) to its actual phenological stage, expressed on universal BBCH (Biologische Bundesantalt, Bundessortenamt and Chemische Industry) phenological scale (Meier et al., 2001). Using TableCurve® 2D 5.01 (SYSTAT Software Inc., CA, 2002), the following asymptotic function (Eq. (1)), typical of apple development (Denne, 1963), was fitted to the values of the BBCH scale as a function of the equivalent in DFB.

$$\mathrm{BBCHscale} = 65 + (A - 65) \times (1 - e^{(-B(\mathrm{DFB} - C))}) \quad (1)$$

In Eq. (1), parameter A is the maximum value on the BBCH scale, parameter B is a rate of increase of the BBCH scale and C is a parameter that allows horizontal translocation of the curve. In the case of 'Honeycrisp' apples from Frelighsburg in 2010 and 2011, values for the parameters were the following: $A = 82.42$, $B = 0.015$ (2010) or 0.0165 (2011), and $C = 0$, with an R^2 value of 0.97 for the curve-fitting. The resulting BBCH values linked to specific values of DFB as follows: 0 DFB at BBCH 65, 30 DFB at BBCH 71, 60 DFB at BBCH 75 and 90 DFB at BBCH 78. For each harvest site from 2002 to 2006 and 2009 to 2011, the same asymptotic function was fitted to the two measured BBCH stages: full bloom (65) and harvest (80).