Erratum

The influence of pre-storage delayed cooling on quality and disorder incidence in ‘Honeycrisp’ apple fruit

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Abstract

The influence of a pre-storage, 7-day, 20 °C warming period on post-harvest apple (Malus ×domestica Borkh.) fruit quality and disorder expression—soft scald and low temperature breakdown in particular, were investigated in ‘Honeycrisp’ fruit grown in the Annapolis Valley of Nova Scotia. The apples from 7-year old trees were harvested from three commercial sites on Sept 30, 2002 (early) and Oct 10, 2002 (late), after which, half of the fruit was immediately cooled to 5 °C (control), while the other half was held for 7 days at 20 °C (delayed cooling treatment). Both the control and delay cooled apples were then stored at either 3 °C or 5 °C in controlled atmosphere (CA) (2.5 kPa O2; 1–1.5 kPa CO2) or refrigerated air (RA) storage for 4 and 6 months. Fruit quality measurements and disorder incidence were recorded following storage removal and a 7-day shelf-life at 20 °C. Delayed cooling had no effect on fruit firmness, soluble solids (%), titratable acidity, epidermal greasiness, senescent breakdown, and bitter pit (the incidence of these latter disorders was low), while moisture loss from the delay cooled fruit ranged from 1.2 to 1.3% following the 7-day treatment. Delayed cooling strongly suppressed the development of the storage disorders soft scald and low temperature breakdown, which in the control fruit reached upwards to 30% of the sample. No CA- or RA-related differences in these disorders were observed in the fruit receiving the pre-storage delayed cooling treatment. Storage rot was not influenced by delayed cooling and was present in upwards to 32% of the fruit from the late-harvested apples after 6 months of storage. In regions where soft scald and low temperature breakdown are serious postharvest problems, it appears that a delayed cooling period prior to storage will help minimize economic loss.

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1. Introduction

The apple (Malus ×domestica Borkh.) cultivar ‘Honeycrisp’ was developed in Minnesota and released in 1991 (Bedford, 2001). Since then, ‘Honeycrisp’ has become very popular in the fresh fruit market in the northern US and eastern Canada resulting in premium prices for growers. ‘Honeycrisp’ fruit has shown a tendency to develop soft scald as well as several other quality-related problems (e.g., bitter pit, watercore, low temperature breakdown, skin punctures, and decay), which vary in severity with the growing region. These problems threaten the horticultural adoption of this potentially profitable cultivar (Clements et al., 2001; Evans, 2001; Greene
and Weis, 2001; Schwallier, 2001; Prange et al., 2002).

In Nova Scotia, soft scald is the most frequently observed storage disorder, sometimes reaching 100% incidence after harvest followed by low temperature breakdown and watercore (Prange et al., 2002; Prange and DeLong, unpublished data). Meheriuk et al. (1994) noted that soft scald is a low-temperature disorder and is likely to occur when highly respiring susceptible cultivars are cooled rapidly. Since it is induced by storing fruit at 2.2°C or lower, Meheriuk et al. (1994) recommend storage at temperatures not lower than 2.5°C for the first 6–8 weeks. Although a number of additional solutions to control soft scald have been proposed, e.g., early harvest, avoiding delays in cooling, 20–30% CO2 for 2 days during the cooling period, 38–42°C for 8–12 h before cooling (Meheriuk et al., 1994; Bedford, 2001; Schwallier, 2001), none have been tested on regionally grown ‘Honeycrisp’.

‘Honeycrisp’ fruit can develop a cortical browning which has been called soggy breakdown (Watkins and Rosenberger, 2002), an uncommon disorder well-described by Smock (1977), but not recognized by Meheriuk et al. (1994) as being distinct from low-temperature breakdown. As photographs of soggy breakdown (Watkins and Rosenberger, 2002) are identical to those of cortical low temperature breakdown (Meheriuk et al., 1994), we refer to this disorder in this report as low temperature breakdown.

Prange et al. (2002) observed that low temperature breakdown, watercore, and scald scald occur in ‘Honeycrisp’ fruit harvested early and stored immediately at 3°C in controlled atmosphere (CA), whereas late-harvested fruit having a 4-week storage period at >3°C before CA storage at 3°C developed very few disorders. These observations indicate that there are one or more significant factors in controlling ‘Honeycrisp’ storage disorders including: (1) storage temperature (i.e., 3°C, may be too cold); (2) timing of harvest (early versus late) and storage regime [refrigerated air (RA) versus CA]; and (3) a cooling delay between harvest and CA or RA storage may be beneficial.

Therefore, the objective of this study was to examine the influence of delayed cooling, timing of harvest, storage temperature, and CA versus RA environments on the occurrence of soft scald, low temperature breakdown, and other quality-related problems in Nova Scotia-grown ‘Honeycrisp’ fruit.

2. Materials and methods

2.1. Plant material and storage conditions

‘Honeycrisp’ apples from 7-year old trees on M26 rootstock were harvested early (Sept 30, 2002) and late (Oct 10, 2002) from three commercial orchards in the Annapolis Valley of NS with each orchard being treated as an experimental replicate. Half of the fruit were immediately cooled over 24 h to 5°C and were then stored at 3 or 5°C in either refrigerated air or controlled atmosphere (2.5 kPa O2, 1–1.5 kPa CO2), while the other half was kept at 20°C for 7 days (delayed cooling) and were then stored at 3 or 5°C with the control samples for 4 and 6 months in either RA or CA environments. In both the RA and CA storage regimes, the fruit were placed in top-loading 0.34 m3 cabinets; those in the CA environment were flushed with nitrogen gas until O2 levels of 1.5% were obtained. The CA atmosphere was monitored and controlled by a David Bishop Instrument Oxystat® 2002 system (Bacharach Europe, Warwickshire, UK).

2.2. Quality and disorder measurements

Apple weight loss (i.e., moisture loss) was determined as the difference in the weight of the apples before and after the 7-day pre-storage warming period. Following 4 and 6 months of storage, 15 fruits were removed from each treatment combination: 10 apples were immediately measured after warming at 20°C and five were held for a shelf-life period of 7 days at 20°C. Fruit firmness (N) was measured on the red and green sides of individual apples with the fruit quality testor (Geo-Met Instrument, New Minas, NS), having the time limit window set at >0.1 and <1.0 s (DeLong et al., 2000). Soluble solids content and titratable acidity were measured on the 10-apple composite juice sample with a hand-held refractometer (Atago Co., Tokyo) and by titration of 2 mL apple juice with 0.1 mol L−1 sodium hydroxide, respectively. The latter was expressed as mg equivalents of malic acid per 100 mL juice (DeEll and Prange, 1998).
After fruit removal from storage and 24 h at 20 °C, ethylene evolution rates (μL L⁻¹ per 100 g fruit) for each treatment were measured on five-apple samples placed in 4 L mason jars with air flow rates across the fruit of 20 mL min⁻¹. Following equilibration, a 1 mL gas sample was withdrawn by a syringe from each jar outlet line and injected into a gas chromatograph (GC) (Carle Instruments Inc., Anaheim, California) equipped with a 1.9 m x 3.2 mm (o.d.) stainless steel column packed with activated alumina with helium carrier flow at 50 mL min⁻¹ and a flame ionization detector. Quantitation was performed by comparison of the GC response of the sample to that of a certified standard (DeEll and Prange, 1998).

The incidence of bitter pit, soft scald, low temperature breakdown, senescent breakdown, and rotted fruit was assessed as percentages of the total fruit on the 10-apple sample following removal from storage and on the five-apple sample following the 7-day shelf-life. Epidermal greasiness was evaluated on a 0–3 scale, where: 0, none; 1, slight; 2, moderate; and 3, severe and unmarketable.

### 2.3 Experimental design and statistics

The experiment was planned as a randomized complete design with factorial combination of five treatments: harvest (early and late), pre-storage conditioning [control (none) and 7 days at 20 °C], storage regime (RA and CA), storage temperature (3 and 5 °C) and storage duration (4 and 6 months) with each treatment combination being replicated three times (grower: rep). Following the 7-day shelf-life, the two pre-storage conditioning treatments were compared at the 4- and 6-month removals for each combination of harvest, storage regime, and storage temperature by the LSMean option of SAS’s PROC GLM (SAS Institute, 1994).

### 3. Results and discussion

Delayed cooling did not affect ‘Honeycrisp’ firmness, soluble solids, and titratable acidity in early- or late-harvested fruit held for 4 or 6 months in RA or CA storage (data not shown). The most striking observation in this experiment was that delayed cooling markedly suppressed not only cortical low temperature breakdown but also soft scald, regardless of the timing of harvest, storage regime, duration, and temperature (Table 1A and B). Meheriuk et al. (1994) recommended delayed cooling and fruit moisture loss for control of low temperature breakdown but not for soft scald. Both disorders are thought to be induced by low storage temperatures (Meheriuk et al., 1994; Watkins and Rosenberger, 2002), although it is unknown how low chilling temperatures stimulate the cellular triggers that cause disorder expression. Interestingly, periodic fruit warming prior to and during storage reduces the incidence of superficial scald—a postharvest disorder also described as chilling injury (Watkins et al., 1995; Alwan and Watkins, 1999). Watkins et al. (1995, 2000) suggest that fruit warming ameliorates superficial scald susceptibility through: (a) catabolism of toxic substances that accumulate at lower temperatures; (b) an increase in fatty acid unsaturation; and (c) an increase in endogenous antioxidant compounds. Soft scald has been associated with a low level or loss of the 18:2 polyunsaturated fatty acid, linoleic acid (Wills, 1973; Hopkirk and Wills, 1981) as well as an increase in the six carbon alcohol, hexanol (Wills, 1973). Exposure to chilling temperatures can increase phospholipid D activity which provides free fatty acid substrate for lipoxigenase (LOX) (Pinheiro et al., 1998). In addition, enzymatic degradation of linoleic acid via the LOX cascade generates hexanal (Luning et al., 1995; Rowan et al., 1999), which when applied exogenously, induces soft scald symptoms (Wills, 1973).

The average water loss from the delayed cooled fruit immediately following the treatment ranged from 1.2 to 1.3% (Table 1A and B). Past research has demonstrated that moisture loss from ‘McIntosh’ apples is associated with a reduction in senescent and low temperature breakdown (Blanpied, 1981) as well as brown core (Lidster, 1990). A moisture loss induced reduction of acetate esters is also associated with a decrease in low temperature breakdown in ‘Jonathan’ fruit, perhaps due to the carrier effect of evaporating water on certain volatile compounds (Wills, 1968). The biochemical linkages between water loss, fatty acid oxidation, and the volatile compound chemistry that specifically affect low temperature-related disorder expression in ‘Honeycrisp’ are presently unknown but merit further investigation.
Table 1

<table>
<thead>
<tr>
<th>Harvest Storage (months)</th>
<th>Temperature (°C)</th>
<th>Low temperature breakdown* (%)</th>
<th>Soft scald (%)</th>
<th>Rot (%)</th>
<th>Ethylene (per 100 g fruit) (µL L⁻¹)</th>
<th>Weight loss (%)</th>
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* Low temperature breakdown: soggy breakdown.

Table means (except ethylene) were derived from measurements taken immediately following storage and 7 days at 20 °C (6 reps × 5 fruit rep⁻¹ × 90 fruit); all values are in percentages. Ethylene means were calculated from a 15-apple composite sample (3 reps × 5 fruit rep⁻¹ × 15 fruit); 24 hours after storage removal. Control (0) and 7 days means were separated by SAS’s LSMeans procedure with statistically significant differences being indicated by (*) 0.05 < P < 0.10 or (**) P ≤ 0.05.

For the fruit that were not delayed cooled, low temperature breakdown tended to be more severe in the late-harvested apples (Table 1A and B). ‘Honeycrisp’ fruit exposed to a pre-storage delayed cooling period appeared to respond as well in the CA as in the RA environment (Table 1A and B). Thus, CA storage appears to be a viable option for this cultivar. The incidence of other disorders such as bitter pit, senescent breakdown, and fruit greasiness were not severe and were not influenced by the delayed cooling period (data not shown). Bitter pit, in particular, is a serious post-storage disorder in most of the regions where ‘Honeycrisp’ is grown; however, it has not been a problem in Nova Scotia to date.

Although rot incidence was not influenced by delayed cooling, storage temperature or regime, it increased in late-picked fruit (Table 1A and B). As storage rot is a major problem for this cultivar (Greene and Weis, 2001; Prange et al., unpublished data), preharvest fungicidal sprays or a pre-storage fungicidal dip may be a necessary procedure for reducing storage decay.

Ethylene evolution in delayed cooled ‘Honeycrisp’ fruit was lower than in non-treated apples following CA storage in particular (Table 1A and B) suggesting a negative association between moisture loss and the rate of cellular metabolism. Prange et al. (2001) also observed a moisture loss associated decrease in res-
piration in ‘McIntosh’ fruit following 4 and 8 months of CA storage; in their study, however, water loss was facilitated by calcium chloride salt solutions and not by a pre-storage delayed cooling period. Ironically, ethylene exposure has been shown to reduce chilling injury in other fruits such as tomato (Hong and Gross, 2000) and muskmelons (Lipton and Aharoni, 1979), and reduces chilling-induced woolliness in peaches (Palou et al., 2003) and nectarines by promoting ripening-related changes both during and after storage (Dong et al., 2001). It may be that fruit moisture loss concomitant with the potential increase in the ethylene generation that occurred during the 7-day delayed cooling period synergistically contributed to reducing chilling injury in the ‘Honeycrisp’ fruit.

In conclusion, the delayed cooling treatment of 7 days at 20°C prior to storage at 3 or 5°C resulted in marked or complete suppression of soft scald and low temperature breakdown in early- and late-harvested ‘Honeycrisp’ fruit following 4 or 6 months of CA or RA storage. Delayed cooling also decreased the rates of ethylene evolution but did not affect the incidence of storage rot. For regions in which soft scald and low temperature breakdown cause significant economic loss, delaying the cooling of fruit prior to storage appears to be a beneficial step in minimizing disorder incidence.

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References


