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Impact of 1-methylcyclopropene and controlled atmosphere on the quality of stored 'AC Harrow
Crisp' pears

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ABSTRACT

‘AC Harrow Crisp’ pears could be stored at 0 °C, without or with controlled atmosphere (18 or 2.5 kPa O₂, 2 kPa CO₂) for 111 days with little effect on overall quality. 1-Methylcyclopropene-treated fruit could be stored for longer periods under refrigerated air, but not under controlled atmosphere.

Keywords: European pear; internal breakdown; internal cavity; postharvest physiology; senescent scald.

INTRODUCTION

The majority of European pears (*Pyrus communis* L.) cultivated in Canada are directed to domestic retailers; an ongoing challenge is that 90% of this market is dominated by foreign competition (Agriculture and Agri-Food Canada 2015). The development of optimal postharvest handling strategies is required for better marketing of Canadian-grown pears. In other geographical regions, pears are stored under low temperatures (e.g., -1 to 1 °C) and often with controlled atmosphere (CA; low O₂ and elevated CO₂ partial pressures) in order to extend the commercial marketing period (Lum et al. 2016b). These postharvest handling strategies offset fruit senescence by limiting respiration and ripening due to ethylene (Lum et al. 2016b). For some cultivars, prolonged storage under low temperatures and/or CA elicits the development of senescence-related disorders, such as senescent scald and internal breakdown (DeEll and Ehsani-Moghaddam 2011; Lum et al. 2016b, 2017). In addition, CA-related injuries such as internal CO₂ injury/cavities can occur in pears (Deuchande et al. 2016; Lum et al. 2016b).

The ethylene antagonist 1-methylcyclopropene (1-MCP) is used commercially to limit ripening and senescence of climacteric fruit, including European pears (Watkins 2006). Our previous research revealed that 1-MCP and storage at 0 °C, 2.5 kPa O₂ and 2 kPa CO₂ effectively controls the development of senescent scald and internal breakdown in ‘Swiss Bartlett’ and ‘Cold Snap’ pears (Lum et al. 2017). ‘Cold Snap’ and ‘AC Harrow Crisp’ are newly developed Ontario pear cultivars that are resistant to fire-blight (Hunter et al. 2002, 2009), which is an orchard-borne disease leading to widespread economic losses in the production of traditional cultivars, such as ‘Bartlett’. ‘AC Harrow Crisp’ is a midseason pear with highly preferred flavour and texture properties (Hunter et al. 2002). Current storage recommendations indicate that pears of this cultivar can be cold stored for up to 4 months (DeEll and Slingerland 2012), but there is no knowledge on whether storability can be enhanced by 1-MCP and/or CA. In the present study, we determined the impact of 1-MCP and CA (18 or 2.5 kPa O₂, 2 kPa CO₂) on the rates of ethylene production, firmness, peel colour, titratable acidity, the levels of soluble solids and starch, and the incidence of physiological disorders in ‘AC Harrow Crisp’ pears stored at 0 °C for up to 170 d.

MATERIALS AND METHODS

‘AC Harrow Crisp’ pears (410 kg) were harvested at commercial maturity on August 24, 2012 from a commercial orchard near Simcoe, Ontario, Canada. Pears were randomly and evenly distributed into 24 boxes, and then transferred to the University of Guelph storage facility within 4 h of harvest. Half of the boxes containing pears were treated with 300 nL L⁻¹ gaseous 1-MCP (SmartFreshTM, AgroFresh Inc., Spring House, PA, USA) for 24 h at 23 °C, whereas the remaining boxes were untreated, as described previously (Lum et al. 2017). Thereafter, all fruit

were transferred to four separate refrigeration rooms set to 0 °C and subjected to three storage regimens. Each room contained two CA chambers (0.5 m³, Storage Control Systems, Sparta, MI, USA), with each chamber containing one box of 1-MCP-treated and one box of non-1-MCP-treated 'AC Harrow Crisp'. CA regimens of 18 kPa O₂/2 kPa CO₂ and 2.5 kPa O₂/2 kPa CO₂ were achieved in the sealed chambers and monitored periodically as described previously (Lum et al. 2017). In addition, one box each of non-1-MCP-treated fruit and 1-MCP-treated fruit were left under ambient air present in the refrigeration room. Thus, each refrigeration room contained one replicate of each 1-MCP/storage regimen treatment. For each treatment replicate, fruit were sampled at 6, 13, 34, 55, 111 and 170 d of storage, where 10 pears were chosen randomly for assessment of fruit quality attributes on each sampling day.

On the day of harvest, fruit firmness, peel surface colouration, titratable acidity, and the levels of soluble solids and starch were assessed on three replicates of 10 pears that were collected from various locations within the orchard, using previously published protocols (Lum et al. 2017). For each replicate, the rate of ethylene production was assessed on three representative fruit as described by Lum et al. (2017). For each 1-MCP/storage regimen replicate (4 replicates of 10 fruit), the ripening attributes were assessed within 6 h of their removal from storage. These same fruit were evaluated for the incidence of senescent scald (browning of the peel), internal cavities, and internal breakdown (diffuse browning of the flesh).

Statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC; $\alpha=0.05$). ANOVAs (proc mixed method) were used to analyze the effects of room, 1-MCP, CA regimen, and storage time and their interactions. For all significant interactions ($P<0.05$), a Fisher's protected least significant difference (LSD) test (with slice option) was used to compare treatment means at each sampling time. Similarly, a Fisher's protected LSD test was used to

compare differences within each treatment over the storage period; treatment replicate data were pooled across repeated measures. Data expressed as percentages (i.e., physiological disorders) were arcsine square root transformed to ensure a normal distribution of variance and the treatment means were back-transformed for presentation.

RESULTS

Fruit quality was assessed at harvest and after storage. Fruit ripening attributes were not assessed in non-1-MCP-treated pears stored under refrigerated air for 170 d due to the high severity of physiological disorders. All pears lacked the capacity to produce ethylene at harvest and during the first 34 d of storage (Fig. 1A). By 111 d, the 1-MCP-treated pears produced 84-94% less ethylene than untreated fruit, and refrigerated air-stored fruit exhibited yellow fruit peel colouration (Fig. 1B). Notably, peel yellowing was delayed by 59 d with 1-MCP at 18 kPa O₂ and with 2.5 kPa O₂ in non-1-MCP-treated fruit. By 170 d, yellow-green colouration was evident in 1-MCP-treated fruit at 2.5 kPa O₂. Firmness levels were well maintained during storage, and there was no impact of either 1-MCP or CA (Fig. 1C). None of these postharvest handling treatments affected the accumulation of soluble solids or decreases in titratable acidity and starch content (Supplementary Fig. S1).

Senescence-related disorders were absent during the first 111 d of storage. Non-1-MCP fruit held under refrigerated air displayed a high incidence of senescent scald after 170 d, which was reduced by 15% and 81% at 18 and 2.5 kPa O₂, respectively (Fig. 1D). The incidence of this disorder was never higher than 10% in all 1-MCP-treated pears. Internal breakdown developed most in non-1-MCP-treated fruit held under refrigerated air (Fig. 1E). The incidence level of this disorder was reduced by 25-39% in fruit stored at 2.5 kPa O₂-stored fruit; marginal levels were

apparent for all other treatments. Internal cavities became visible in all 1-MCP fruit after 111 d of CA storage, and the incidence increased thereafter. Internal cavities were negligible for all other treatments (Fig. 1F).

DISCUSSION

In the present study, we tested the separate and combined effects of 1-MCP and CA on the quality of 'AC Harrow Crisp' fruit stored for up to 170 d. 1-MCP and CA blocked the production of ethylene and delayed fruit peel yellowing. Similar effects of 1-MCP occur in chilled 'Bartlett' and 'Swiss Bartlett' pears held at 2.5 kPa O₂ (DeEll and Ehsani-Moghaddam 2011; Lum et al. 2017). 'AC Harrow Crisp' pears softened very little with storage. This is consistent with minor losses of firmness in 'Cold Snap' fruit during chilling and/or CA storage; conversely, non-1-MCP-treated 'Swiss Bartlett' fruit soften under similar conditions in a process limited by 1-MCP (Lum et al. 2017). In the absence of 1-MCP, the preservation of firmness in 'AC Harrow Crisp' pears could be due to its lower ethylene production capacity relative to 'Swiss Bartlett' stored under similar conditions (Lum et al. 2017).

The highest level of control for senescence-related disorders in 'Swiss Bartlett' and 'Cold Snap' pears occurs with pre-storage application of 1-MCP followed by storage at 0 °C, 2.5 kPa O₂, 2 kPa CO₂ (Lum et al. 2017). Non-1-MCP-treated 'AC Harrow Crisp' pears held under air at 0 °C exhibited the highest incidence of senescent scald and internal breakdown after 170 d of storage. Conversely, 1-MCP had no effect on the high incidence of internal breakdown in 'AC Harrow Crisp' pears at 2.5 kPa O₂. Moreover, 1-MCP induced the formation of internal cavities during prolonged CA storage; this appears to be a CO₂-related injury as both regimens included 2 kPa CO₂. CO₂-related internal browning occurs in 'Rocha' pears (Deuchande et al. 2016), but

to our knowledge, this is the first report demonstrating a negative impact of 1-MCP on CO₂-related injury (i.e., internal cavities) in pear fruit. Previous research has shown that 1-MCP exacerbates CO₂-related injury in ‘Honeycrisp’ apples (DeEll et al. 2016), and its development is associated with the accumulation of the oxidative stress metabolite γ -aminobutyrate (Lum et al. 2016a). Thus far, it is known that visible symptoms of internal breakdown and senescent scald in ‘Cold Snap’ and ‘Swiss Bartlett’ pears develop after the decline in the whole fruit glutathione levels (Lum et al. 2017). It is tempting to speculate that physiological disorders in ‘AC Harrow Crisp’ fruit are associated with shifts in oxidative stress metabolism, but to date this has not been investigated. Overall, it appears that ‘AC Harrow Crisp’ pears can be stored at 0 °C without or with CA for 111 d with little effect on overall fruit quality; 1-MCP-treated fruit can be held at 0 °C under air for longer periods, but not CA.

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Figure Legends

Fig. 1. The impact of 1-MCP and CA on ripening attributes and physiological disorders in stored ‘AC Harrow Crisp’ pears. Fruit were treated with or without 1-MCP on the day of harvest and stored at 0 °C under air or CA of 18 or 2.5 kPa O₂, and 2 kPa CO₂. No 1-MCP (closed black squares); 1-MCP (open grey squares). Ethylene production rates (A), surface peel colouration (B) and firmness (C) were assessed at harvest and within 6 h of the transfer of fruit from storage to 22 °C. A subjective scale was used for peel surface colour: 1 = green, 2 = more green than yellow, 3 = more yellow than green, 4 = yellow. The incidence of senescent scald (D), internal breakdown (E) and internal cavities (F) was calculated as the percentage of sampled fruit exhibiting specific disorder symptoms. The rate of ethylene production at harvest (d 0 of storage minus 1 d) represents the mean of three biological replicates of three fruit each; for all other ripening attributes, data at harvest represent the mean of three biological replicates of ten fruit each. For each postharvest treatment, the rates of ethylene production (d 6 to 170 of storage) represent the mean of four storage replicates of three fruit each, whereas data for all other ripening attributes and physiological disorders at those sampling times represent the mean of four storage replicates of ten fruit each. Similar letters at each time point or within a treatment indicate no significant difference at $P \leq 0.05$ level. Within each treatment, capital letters denote

significant differences over storage time; small letters denote significant differences across all six 1-MCP/storage regimen treatments. For each plot within A-F, black and grey letters correspond to the nearest non-1-MCP or 1-MCP datum, respectively.

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