Integrated Ethylene and Temperature Conditioning for Induction of Ripening Capacity in 'Anjou' and 'Comice' pears

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Abstract

'Anjou' and 'Comice' pears from three harvest dates were conditioned to develop ripening capacity by exposure to 100 µL L^{-1} ethylene at 20 °C for 0, 24, 48, or 72 h, followed by varying durations of temperature conditioning at -0.5 or 10 °C. Ripening capacity was tested by measuring fruit firmness at 7 d at 20 °C after completion of conditioning treatments. Fruit firmness was also measured after conditioning but before ripening, and was designated "shipping firmness," indicative of the potential for the fruit to withstand transport conditions without physical injury. Ripening capacity in both cultivars developed more rapidly with later harvest date, increasing duration of ethylene conditioning, and increasing duration of temperature conditioning. Ripening capacity developed much more rapidly at 10 °C than at -0.5 °C. Useful durations of temperature conditioning at 10 °C were limited by fruit softening below acceptable values of shipping firmness. However, sequential combinations of ethylene and temperature

conditioning at both -0.5 and 10 °C were identified wherein post-conditioning shipping firmness was acceptable.

Keywords: *Pyrus communis*; pear conditioning; pear ripening

1. Introduction

Winter pear cultivars (*Pyrus communis* L.) generally require exposure to low temperatures or to ethylene gas after harvest in order to develop the capacity to ripen when subsequently maintained at warm temperatures (Hansen and Mellenthin, 1979; Villalobos-Acuña and Mitcham, 2008). The typical minimum low temperature exposure duration for induction of ripening capacity in 'Anjou' pear is approximately 60 d (Chen and Mellenthin, 1981; 1982), and in 'Comice' pear is approximately 30 d (Elgar et al., 1997; Miró et al., 2001; Ma and Chen, 2002; Sugar and Basile, 2006). During postharvest low temperature exposure, pear fruit develop the capacity to produce ethylene internally at a sufficient rate to activate and complete the ripening process, including tissue softening (Agar et al., 2000a; Blankenship and Richardson, 1985; Chen and Mellenthin, 1981; Knee, 1987; Murayama et al., 1998). This method of inducing pear ripening capacity is known as "satisfying the chilling requirement" or "temperature conditioning" (Blankenship and Richardson, 1985; Porritt, 1964; Villalobos-Acuña and Mitcham, 2008). Villalobos-Acuña and Mitcham (2008) applied the terms "ethylene conditioning" and "temperature conditioning" to distinguish the two approaches to induction of pear ripening capacity. Although in commercial practice temperature conditioning is typically accomplished near the coldest temperature tolerated by the fruit (-0.5 to -1.6 °C), coincident with the optimum temperature for long-term storage (Porritt, 1964), previous research suggested that

conditioning could be accomplished more rapidly at 5 or 10 °C (Gerasopoulos and Richardson, 1999; Mitcham et al., 2000; Sfakiotakis and Dilley, 1974). Subsequently, 10 °C was identified as the most efficient temperature for inducing ripening capacity in 'Anjou' and 'Comice' pears (Sugar and Einhorn, 2011; 2012).

Exogenously-applied ethylene can stimulate internal ethylene generation and consequent development of ripening capacity in pears (Blankenship and Richardson, 1985). Ethylene conditioning of pears is effective when applied at approximately 100 µL L^{-1} at 20 °C (Chen, 2000; Chen et al., 1997a; Sugar and Basile, 2006). In applying ethylene conditioning as a means to have ripening-capable pears available for earliest marketing after harvest, the duration of exposure to ethylene is critical in both 'Anjou' (Chen et al., 1997b) and 'Comice' (Sugar and Basile, 2006). Pears of these cultivars harvested at earliest maturity need approximately 72 h of ethylene conditioning in order to fully develop ripening capacity. Nevertheless, industry standards indicate a minimum of 24 h treatment in 100 µL L^{-1} ethylene to describe the fruit as "conditioned", and several pear packers indicated in a survey that no more than 24 h were given to 'Anjou' pears in their conditioning program (Pear Bureau Northwest, 2010). Sugar and Einhorn (2012) found that after 24 h in 100 µL L^{-1} ethylene at 20 °C, 'Anjou' pears harvested at the earliest acceptable maturity needed an additional 30 d at -0.5 °C to develop ripening capacity, and after 48 h in ethylene an additional 20 d were needed. In contrast, in 'Bartlett' pears, treatment with 100 µL L^{-1} ethylene for 24 h at 20 °C obviates the need for postharvest chilling and promotes uniformity of ripening among individual fruit (Agar et al., 1999, 2000b; Puig et al., 1996; Mitcham and Mitchell, 2007).

Fruit maturity at harvest has a significant effect on the amount of time required at temperatures below 0 °C for successful conditioning (Chen and Mellenthin, 1982; Elgar et al.,

1997). The duration of conditioning decreases gradually and linearly as maturity at harvest advances within the range of acceptable harvest maturity in 'Anjou' and 'Comice' pears (Sugar and Basile, 2009; Sugar and Einhorn, 2011). Fruit maturity in pear is commonly estimated by measurement of fruit firmness (Kingston, 1992; Kupferman and Dasgupta, 2001). Fruit firmness declines with advancing maturity and with duration of postharvest storage (Chen and Mellenthin, 1981; Porritt, 1964). Fruit with diminished firmness have a greater susceptibility to various types of physiological and mechanical injury during postharvest handling and during transport to markets (Mitcham and Mitchell, 2007; Thompson, 2007).

Although increasing duration of exposure to ethylene and increasing duration of post-ethylene temperature conditioning can reduce the time needed to induce ripening capacity in 'Anjou' and 'Comice' pears, fruit at the conclusion of conditioning may be too soft for shipment to markets without increased risk of physical injury. The objective of this study was to determine the effects of sequential treatments of ethylene conditioning for 0-72 h followed by temperature conditioning at -0.5 or 10 °C on fruit firmness after conditioning but before initiation of ripening (designated as "shipping firmness") and on the development of ripening capacity in fruit harvested at three stages of maturity.

2. Materials and Methods

2.1. Fruit

'Anjou' pears were harvested weekly for 3 weeks in 2010 and 2011 from mature trees in the orchard of the Southern Oregon Research and Extension Center (SOREC) near Medford, Oregon (42.3 °N, 122.8 °W, elevation 455 m). 'Comice' pears were similarly harvested from a nearby commercial orchard. In each orchard, four replicate groups of trees within a 0.5 ha block were

used as sources of fruit, and this field replication was maintained throughout the subsequent postharvest experiments. In each year, harvest began when the fruit in the orchard reached maturity, defined as when the average firmness of a 10-fruit sample, tested in two locations on opposite sides of each fruit, became < 66.7 N for 'Anjou' or < 57.8 N for 'Comice' (Hansen and Mellenthin, 1979; Sugar, 2007). The first harvest day was designated Day 0, and subsequent harvests as Day 7 and Day 14. Fruit firmness was measured using a Fruit Texture Analyzer (Güss Manufacturing, Strand, South Africa) fitted with an 8 mm diameter probe. Measurements were made in the widest part of the fruit after a 1-2 cm diam area of peel was removed from the area to be tested, using a kitchen peeler.

2.2. Ethylene conditioning

On each harvest day, 400-560 fruit were harvested from each orchard replicate and transported to the laboratory at SOREC. Fruit firmness was measured on 10 fruit per replicate as described above as an indicator of harvest firmness, and 10 fruit per replicate were placed on a lab bench at 20 °C to test ripening capacity without conditioning. After 7 d at 20 °C, fruit firmness was measured. Fruit were considered ripe if the average firmness after 7 d at 20 °C was < 17.8 N (4 lbf). The remaining fruit were treated with ethylene at 20 °C for 0, 24, 48, or 72 h. Ethylene was introduced into a sealed room from a cylinder to a concentration of approximately 100 µL L^{-1} as determined using a gas chromatograph (Model AGC Series 400, Hach Carle, Loveland, CO) operated at 70 °C with an alumina column and flame ionization detector. After each 24 h period, the room was ventilated prior to removal of samples, then re-sealed and an atmosphere of 100 µL L^{-1} ethylene was re-established.

2.3. Post-ethylene temperature conditioning

Fruit firmness after conditioning but before ripening was considered the "shipping firmness," reflecting fruit vulnerability to physical injury during shipment. Based on personal inquiries of pear producers in the Pacific Northwest, fruit firmness values > 44.5 N (10 lbf) were considered suitable for shipping to all destinations within the continental United States by normal means. Fruit with firmness values < 44.5 N but > 35.6 N (8-10 lbf) were considered not suitable for long-distance shipping, but likely to be suitable for moderate and short-distance shipping. Fruit with firmness values < 35.6 N (8 lbf) were considered unsuitable for any but local shipping.

Immediately following each ethylene treatment, 10 fruit per replicate were measured for fruit firmness, and 10 fruit per replicate were placed on a lab bench at 20 °C to test ripening capacity without additional temperature conditioning. Fruit firmness was measured on those fruit after 7 d at 20 °C. The remaining fruit were transferred to regular air storage rooms maintained at either -0.5 or 10 °C. After varying durations of temperature conditioning following each duration of ethylene conditioning, 20 fruit per replicate were removed. Fruit firmness was measured on 10 fruit per replicate per treatment at the end of conditioning, considered representative of the "shipping firmness" were the fruit to be marketed under commercial conditions. The remaining 10 fruit were placed at 20 °C for 7 d, then fruit firmness was measured on each fruit to determine ripeness.

For 'Anjou' pear, the duration of temperature conditioning at -0.5 °C was 0, 40, 50, or 60 d following 0 h in ethylene; 0, 20, 30, or 40 d following 24 h in ethylene; 0, 10, or 20 d following 48 h in ethylene; and 0 or 5 d following 72 h in ethylene. In 2011, an additional duration of 10 d at -0.5 °C following 72 h in ethylene was included. At 10 °C, the duration of temperature conditioning for 'Anjou' pear was 0, 10, or 20 d following 0 h in ethylene; 0, 5, or 10 d

following 24 h in ethylene; 0 or 5 d following 48 h in ethylene, and 0 or 5 d following 72 h in ethylene. In 2011, additional durations of 10 d at 10 °C following 48 and 72 h in ethylene were included.

For 'Comice' pear, the duration of temperature conditioning at -0.5 °C was 0, 5, 10, and 15 d following 0 h in ethylene in 2010, and 0, 20, 25, and 30 d in 2011. Temperature conditioning at 10 °C was 0, 5, 10, and 15 d in both years. Following 24 h in ethylene the duration of temperature conditioning at -0.5 °C was 0, 5, 10, 15 d in 2010 and 0, 10, 15, and 20 d in 2011. Temperature conditioning at 10 °C was 0, 5, and 10 d in both years. Following 48 h in ethylene the duration of temperature conditioning at -0.5 °C in 2010 was 0, 5, 10, and 15 d and 0, 10, 15, and 20 d in 2011. Temperature conditioning at 10 °C was 0 and 5 d in both years. Following 72 h in ethylene the duration of temperature conditioning at -0.5 °C was 0 d in 2010, and 0 and 5 d in 2011. No temperature conditioning at 10 °C was applied to 'Comice' pears following ethylene conditioning for 72 h.

2.4. Statistical analysis

Values for fruit firmness after 7 d at 20 °C following all combinations of harvest date, ethylene treatment, and post-ethylene temperature conditioning for both years of study and both pear cultivars were subjected to ANOVA based on a factorial design using Statistix software v. 9 (Analytical Software, Tallahassee, FL). Post-conditioning fruit firmness was analyzed for each cultivar, year, harvest date and conditioning temperature using ANOVA and firmness means were separated using Fisher's protected LSD test.

3. Results

2.1. Post-conditioning shipping firmness

In ‘Anjou’ pears, all harvest dates, durations of ethylene conditioning and durations of temperature conditioning at -0.5 °C tested resulted in shipping firmness values > 44.5 N, with the exception of late-harvested fruit exposed to ethylene for 72 h followed by no temperature conditioning in 2010 and when followed by 10 d at -0.5 °C in 2011 (Tables 1 and 2). Without ethylene treatment, temperature conditioning at 10 °C for 10 d resulted in shipping firmness values > 44.5 N, with the exception of late-harvested fruit in 2010. Following 24 h of ethylene treatment, 5 d of temperature conditioning at 10 °C resulted in adequate shipping firmness, but shipping firmness was compromised by 10 d at 10 °C, and by 5 d at 10 °C in late-harvested fruit (Tables 1 and 2). After 48 h ethylene, 5 d at 10 °C resulted in shipping firmness > 44.5 N in fruit from the first two harvests, but not from the latest harvest, while after 10 d at 10 °C shipping firmness was < 35.6 for all harvest dates. After 72 h of ethylene conditioning, 5 d or more of subsequent temperature conditioning at 10 °C resulted in shipping firmness values < 44.5 N; early harvested fruit were < 35.6 N firmness when held for 10 d and late harvested fruit were < 35.6 N firmness when held for any duration (Tables 1 and 2).

In ‘Comice’ pears, all harvest dates, durations of ethylene conditioning and durations of temperature conditioning at -0.5 °C tested resulted in shipping firmness values > 44.5 N in 2010 (Table 3). However, in 2011, ethylene conditioning for 48 h followed by temperature conditioning at -0.5 °C for 20 d and ethylene conditioning for 72 h followed by 5 d of temperature conditioning at -0.5°C resulted in shipping firmness values < 44.5 N regardless of harvest date (Table 4). In late-harvested fruit in 2011, compromised shipping firmness also resulted from fruit conditioned for 20 d at -0.5 °C without ethylene or following 24 h in ethylene, and in fruit conditioned 48 h in ethylene followed by 10 d or more at -0.5 °C. Ethylene

conditioning for 72 h without further temperature conditioning resulted in shipping firmness < 44.5 N but > 35.6 N in late-harvested fruit (Table 4). Without ethylene treatment, temperature conditioning at 10 °C for 10 d resulted in adequate shipping firmness for all harvest dates in 2010 and for the earliest-harvested fruit in 2011. Following 24 h ethylene conditioning, shipping firmness was compromised after 10 d at 10 °C in fruit from harvest days 7 and 14 in 2010 (Table 3). In 2011, all temperature conditioning treatments at 10 °C following 24 h in ethylene resulted in low shipping firmness values (Table 4). After 48 h of ethylene conditioning, 5 d of temperature conditioning at 10 °C resulted in shipping firmness values < 44.5 N in both years and all harvest dates. 'Comice' pears were not held at 10 °C following 72 h of ethylene conditioning.

2.2. Induction of ripening capacity

Year, harvest date, ethylene treatment, and post-ethylene temperature conditioning were all significant factors affecting the extent of softening of both 'Anjou' and 'Comice' pears within 7 d at 20 °C (Table 5). Without ethylene treatment, 'Anjou' pears harvested at Day 0 and temperature conditioned at -0.5 °C for 50 d resulted in fruit softening to < 17.8 N after 7 d at 20 °C in 2010, but in 2011 conditioning for 60 d at -0.5 °C was insufficient to induce complete softening (Figs. 1 and 2). Similarly, full ripening capacity was induced in 'Anjou' pears by conditioning at 10 °C without exogenous ethylene within 10 d in 2010, while between 10 and 20 d were required in 2011. Increasing the duration of ethylene exposure reduced the duration of subsequent temperature conditioning necessary to induce ripening capacity at both conditioning temperatures. Ethylene conditioning for 24 h required an additional 20-40 d at -0.5 °C but only 5-10 d at 10 °C to induce ripening capacity, while ethylene conditioning for 48 h required an

additional 20 d or more at -0.5 °C or 5 d at 10 °C (Figs. 1 and 2). Ethylene conditioning for 72 h was nearly sufficient to induce fruit softening to < 17.8 N after 7 d at 20 ° in 'Anjou' pears harvested on Day 0, and was sufficient in fruit harvested on Days 7 and 14 (Figs. 1 and 2). Fruit softening was further enhanced by temperature conditioning for 5 d at either -0.5 or 10 °C following 72 h in ethylene. Throughout ethylene and temperature treatments, the extent of fruit softening generally increased with later harvest date.

'Comice' pears were only held for a maximum of 15 d of temperature conditioning in 2010, which was insufficient to induce ripening capacity at -0.5 °C without ethylene treatment, but approximately 10 d was sufficient at 10 °C (Fig. 3). In 2011, slightly more than 30 d of temperature conditioning at -0.5 °C were needed to induce ripening capacity without ethylene conditioning, with the duration gradually decreasing with later harvest (Fig. 4). Following 24 h of ethylene conditioning, > 15 d of additional temperature conditioning were necessary at -0.5 °C, but only 5-10 d were necessary at 10 °C (Figs. 3 and 4). After 48 h of ethylene conditioning, 15 d of additional temperature conditioning were needed at -0.5 °C, but 5 d or less at 10 °C. After 72 h of ethylene conditioning, 'Comice' pears were very close to being sufficiently conditioned to soften to < 17.8 N within 7 d at 20 °C without further temperature conditioning, but softening was enhanced by 5 d post-ethylene temperature conditioning at -0.5 °C (Figs. 3 and 4).

4. Discussion

Shipping firmness values at the completion of conditioning treatments tended to decrease with later harvest date, increasing duration of exposure to ethylene, and increasing duration of post-ethylene temperature conditioning. By pairing the data on the combinations of ethylene and

temperature conditioning treatments which are effective for inducing ripening capacity (Figs. 1-4) with the consequences of conditioning treatments on fruit shipping firmness (Tables 1-4), potentially useful treatment combinations can be identified. The applicability of treatment combinations will depend on the specific fruit harvest maturity, duration of ethylene exposure, and duration of post-ethylene temperature conditioning.

Patterns of fruit softening were similar for 'Anjou' and 'Comice' pears, although 'Comice' pears generally require shorter duration temperature conditioning than do 'Anjou' pears (Chen and Mellenthin, 1982; Porritt, 1964; Sugar and Basile, 2006). The duration of temperature conditioning needed to induce ripening capacity in 'Comice' (Sugar and Basile, 2009) and Anjou (Sugar and Einhorn, 2011) pears was previously shown to decrease linearly with advancing fruit maturity at harvest. Despite harvesting at equivalent average firmness values in each year in the present study, there was variation in fruit response to both ethylene and temperature conditioning. Fruit firmness may not be a sufficiently precise indicator of physiological status related to fruit maturity, and other unidentified variable factors related to seasonal weather and tree management may influence fruit response to conditioning.

Villalobos et al. (2011) reported that 'Bartlett' pears treated with 1-methylcyclopropene (1-MCP) and incubated at 10 °C were better able to overcome ripening inhibition than fruit treated with 1-MCP and maintained at 0 °C. Furthermore, preliminary evaluations indicate that temperature conditioning at 10 °C, either alone or following ethylene treatment, may enhance aroma and overall eating quality in 'Anjou' and 'Comice' pears (Makkumrai et al., 2011; Sugar and Einhorn, 2012). Although 'Anjou' and 'Comice' pears may achieve ripening capacity by minimum successful exposure to ethylene or temperature conditioning, optimum eating quality may require longer than minimum exposure durations. Elgar et al. (1997) found that optimum

quality of ‘Comice’ fruit occurred after 8-20 weeks at -0.5 °C, even though fruit softening associated with ripening occurred after 4 weeks. Ma and Chen (2002) observed that ethylene production by ‘Comice’ pears during ripening at 20 °C increased during 3 months at -1 °C when fruit were held beyond the 1 month minimum needed for temperature conditioning. Chen et al. (1983) also noted that softening in ‘Anjou’ pear may occur without development of optimum dessert quality.

5. Conclusions

Temperature conditioning of ‘Anjou’ and ‘Comice’ pears proceeds more rapidly at 10 °C than at -0.5 °C, and can be used as an alternative or complement to ethylene conditioning for reducing the delay in marketing of these pear cultivars while ripening capacity is developed. However, the duration of temperature conditioning at 10 °C must be kept to the minimum necessary to develop ripening capacity, due to the risk of excessive fruit softening and compromised potential for shipping fruit without physical injury. Ethylene conditioning durations of 24 or 48 h are inadequate to induce ripening capacity without further subsequent temperature conditioning in fruit of both cultivars. Although 72 h ethylene conditioning can induce ripening capacity without further temperature conditioning, shorter durations of ethylene exposure followed by temperature conditioning at 10 °C may enhance fruit quality and allow for firmer fruit at shipping. Advancing fruit maturity at harvest increases the extent to which ‘Anjou’ and ‘Comice’ pears will soften during ethylene and temperature conditioning, in turn increasing the likelihood that fruit may be too soft for safe shipping.

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Table 1. Post-conditioning fruit firmness (FF) (shipping firmness) in 'Anjou' pears conditioned in 100 µL L^{-1} ethylene for 0, 24, 48, or 72 h at 20 °C followed by temperature conditioning at -0.5 or 10 °C in 2010.

Anjou 2010		FF (N) after conditioning (shipping firmness)					
		Harvest day					
		0		7		14	
Ethylene conditioning duration (h)	Post-ethylene temperature conditioning duration (d)	Conditioning temperature (°C)		Conditioning temperature (°C)		Conditioning temperature (°C)	
		-0.5	10	-0.5	10	-0.5	10
0	0	65.7 a	65.7 a	59.7 ab	59.7 a	56.9 a	56.9 a
0	5						
0	10		55.2 de		52.9 b		43.5 cd*
0	20		22.5 h**		23.5 e**		20.9 g**
0	30						
0	40	60.7 bc		56.7 bc		54.4 ab	
24	0	62.7 ab	62.7 ab	59.9 a	59.9 a	50.2 bcd	50.2 b
24	5		60.5 bc		54.4 b		47.5 bc
24	10		49.2 f		44.1 c*		36.5 ef**
24	20	60.9 bc		58.3 abc		49.7 bcd	
24	30	60.3 bc		56.7 bc		49.6 cd	
24	40	59.9 bc		57.8 abc		48.3 cde	
48	0	63.7 ab	63.7 ab	59.9 a	59.9 a	51.7 bc	51.7 b
48	5		52.4 ef		45.1 c		40.5 de*
48	10	57.4 cd		56.4 cd		49.2 cde	
48	20	53.4 d		53.4 de		51.8 bc	
72	0	57.7 cd	57.7 cd	51.2 e	51.2 b	44.7 e*	44.7 cd*
72	5	55.3 d	42.4 g*	50.6 e	38.7 d*	45.9 de	32.4 f**

Values in columns followed by the same letter are not significantly different ($P > 0.05$) according to Fisher's LSD.
*indicates values representing $44.8 \geq FF \geq 35.6$, not suitable for long-distance shipping, but may be suitable for moderate-distance shipping; ** indicates values representing $FF \leq 35.6$, which may not be suitable for any but local shipping.

Table 2. Post-conditioning fruit firmness (FF) (shipping firmness) in 'Anjou' pears conditioned in 100 µL L^{-1} ethylene for 0, 24, 48, or 72 h at 20 °C followed by temperature conditioning at -0.5 or 10 °C in 2011.

Anjou 2011		FF (N) after conditioning (shipping firmness)					
		Harvest day					
		0		7		14	
Ethylene conditioning duration (h)	Post-ethylene temperature conditioning duration (d)	Conditioning temperature (°C)		Conditioning temperature (°C)		Conditioning temperature (°C)	
		-0.5	10	-0.5	10	-0.5	10
0	0	66.2 a	66.2 a	60.9 ab	60.9 a	57.4 a	57.4 a
0	5						
0	10		60.9 c		56.8 b		53.4 b
0	20		22.8 h**		21.8 h**		20.2 f**
0	30						
0	40	60.2 d		55.9 cd		54.9 ab	
24	0	64.7 ab	64.7 ab	61.2 ab	61.2 a	56.7 a	56.7 ab
24	5		56.4 d		51.3 c		48.5 c
24	10		43.6 f*		38.1 e*		38.4 d*
24	20	63.4 abc		59.4 abc		58.0 a	
24	30	60.0 d		58.6 abc		54.0 ab	
24	40	61.8 bcd		56.6 cd		55.4 ab	
48	0	66.4 a	66.4 a	61.7 a	61.7 a	54.6 ab	54.6 ab
48	5		49.3 e		44.8 d*		39.4 d*
48	10	63.4 abc	34.6 g**	58.8 abc	28.1 g**	49.5 cd	28.8 e**
48	20	62.7 bcd		57.4 bcd		51.6 bc	
72	0	61.4 cd	61.4 bc	54.4 de	54.4 bc	48.0 cd	48.0 c
72	5	55.5 e	41.3 f*	53.7 de	33.2 f**	45.9 de	30.1 e**
72	10	55.7 e	21.2 h**	51.7 e	16.3 i**	42.5 e*	15.3 g**

Values in columns followed by the same letter are not significantly different ($P > 0.05$) according to Fisher's LSD.
*indicates values representing $44.8 \geq FF \geq 35.6$, not suitable for long-distance shipping, but may be suitable for moderate-distance shipping; ** indicates values representing $FF \leq 35.6$, which may not be suitable for any but local shipping.

Table 3. Post-conditioning fruit firmness (FF) (shipping firmness) in 'Comice' pears conditioned in 100 µL L^{-1} ethylene for 0, 24, 48, or 72 h at 20 °C followed by temperature conditioning at -0.5 or 10 °C in 2010.

Comice 2010		FF (N) after conditioning (shipping firmness)					
		Harvest day					
		0		7		14	
Ethylene conditioning duration (h)	Post-ethylene temperature conditioning duration (d)	Conditioning temperature (°C)		Conditioning temperature (°C)		Conditioning temperature (°C)	
		-0.5	10	-0.5	10	-0.5	10
0	0	57.9 ab	57.9 ab	56.6 a	56.6 a	51.7 a	51.7 ab
0	5	57.8 ab	55.3 c	56.2 a	53.9 abc	51.4 a	52.6 a
0	10	56.8 bc	50.7 d	56.9 a	51.2 c	50.6 ab	45.5 c
0	15	55.6 cd	31.9 f**	52.7 bc	35.3 f**	50.9 a	32.7 e**
24	0	59.6 a	59.6 a	55.2 ab	55.2 ab	51.7 a	51.7 ab
24	5	54.7 cde	51.8 d	54.8 ab	52.3 bc	51.9 a	48.5 bc
24	10	53.4 e	44.6 e*	52.7 bc	38.4 ef*	51.3 a	35.7 de*
24	15	53.4 e		53.0 bc		51.9 a	
48	0	56.7 bc	56.7 bc	54.4 ab	54.4 ab	51.0 a	51.0 ab
48	5	56.2 bcd	42.5 e*	53.5 bc	40.5 e*	50.6 ab	37.8 d*
48	10	54.7 cde		51.0 c		48.5 bc	
48	15	54.4 de		51.3 c		46.4 cd	
72	0	50.3 f	50.3 d	47.0 d	47.0 d	46.0 d	46.0 c

Values in columns followed by the same letter are not significantly different ($P > 0.05$) according to Fisher's LSD.
*indicates values representing $44.8 \geq FF \geq 35.6$, not suitable for long-distance shipping, but may be suitable for moderate-distance shipping; ** indicates values representing $FF \leq 35.6$, which may not be suitable for any but local shipping.

Table 4. Post-conditioning fruit firmness (FF) (shipping firmness) in 'Comice' pears conditioned in 100 µL L^{-1} ethylene for 0, 24, 48, or 72 h at 20 °C followed by temperature conditioning at -0.5 or 10 °C in 2011.

Comice 2011		FF (N) after conditioning (shipping firmness)					
		Harvest day					
		0		7		14	
Ethylene conditioning duration (h)	Post-ethylene temperature conditioning duration (d)	Conditioning temperature (°C)		Conditioning temperature (°C)		Conditioning temperature (°C)	
		-0.5	10	-0.5	10	-0.5	10
0	0	53.3 ab	53.3 a	51.0 a	51.0 a	47.8 a	47.8 a
0	5		54.3 a		50.3 ab		46.8 ab
0	10		44.9 b		41.0 de*		38.7 d*
0	15		27.1 d**		27.2 f**		30.4 e**
0	20	49.8 cde		47.7 bc		43.3 cd*	
24	0	54.0 a	54.0 a	50.3 a	50.3 ab	47.3 a	47.3 ab
24	5		45.5 b		44.4 cd*		39.7 d*
24	10	50.5 cd	26.7 d**	47.8 bc	29.5 f**	45.5 bc	26.0 f**
24	15	48.9 de		47.3 c		46.0 ab	
24	20	48.9 de		46.8 cd		43.8 cd*	
48	0	51.5 bc	51.5 a	49.8 ab	49.8 ab	45.2 bc	45.1 b
48	5		38.4 c*		38.1 e*		32.8 e**
48	10	47.9 ef		46.4 cd		43.9 cd*	
48	15	46.1 fg		44.9 de		41.0 e*	
48	20	43.8 gh*		42.9 ef*		40.9 e*	
72	0	45.1 g	45.1 b	46.4 cd	46.4 bc	42.4 de*	42.4 c*
72	5	41.8 h*		41.8 f*		37.6 f*	

Values in columns followed by the same letter are not significantly different ($P > 0.05$) according to Fisher's LSD.
*indicates values representing $44.8 \geq FF \geq 35.6$, not suitable for long-distance shipping, but may be suitable for moderate-distance shipping; ** indicates values representing $FF \leq 35.6$, which may not be suitable for any but local shipping.

Table 5. Summary of analysis of variance in firmness of ‘Anjou’ and ‘Comice’ pears after 7 d at 20 °C following ethylene and temperature conditioning. Pears were harvested at three weekly dates in 2010 and 2011.

	‘Anjou’			‘Comice’		
Source of variation	df	MS	*P* > F	df[1]	MS	*P* > F
Year (A)	1	1269.2	0.002	1	7579.8	< 0.001
Harvest date (B)	2	1798.2	< 0.001	2	1527.0	< 0.001
Ethylene treatment (C)	3	2243.5	< 0.001	2	6124.0	< 0.001
Post-ethylene temperature (D)	1	17504.5	< 0.001	1	48703.4	< 0.001
A x B	2	55.1	0.651	2	84.2	0.568
A x C	3	318.1	0.060	2	197.0	0.267
A x D	1	934.0	0.007	1	3677.7	< 0.001
B x C	6	48.1	0.894	4	39.2	0.901
B x D	2	636.1	0.007	2	424.5	0.059
C x D	3	565.0	0.005	2	490.7	0.038
A x B x C	6	48.0	0.895	4	48.9	0.858
A x B x D	2	24.7	0.825	2	90.5	0.545
A x C x D	3	127.1	0.396	2	786.1	0.005
B x C x D	6	28.7	0.969	4	8.1	0.994
A x B x C x D	6	22.3	0.984	4	19.5	0.971

[1] Factorial analysis for ‘Comice’ omitted the 72 h ethylene treatment, as that treatment was followed by only one post-ethylene temperature.