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Characterizing the effect of harvest maturity on ripening capacity, postharvest fruit quality, and storage life of 'Gem' pear

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Abstract

'Gem' is a recently-released, unique European pear cultivar that possesses crisp, juicy texture and exceptional eating quality at harvest, but can also ripen to a soft, buttery texture; however, relatively little is known about the optimal harvest maturity (HM) and storage behavior of the fruit. We, therefore, evaluated the effect of HM on postharvest fruit quality attributes of 'Gem' pears [fruit size, flesh pressure (FF), soluble solids concentration (SSC), titratable acidity (TA), and extractable juice (EJ)] in two different seasons. Four and two harvests were performed one week apart in 2011 and 2012, respectively. Fruit were stored in regular air (RA) for 7 months and evaluated monthly, either directly from cold storage (un-ripened), or after provision of a 7 day ripening regime (ripened). Throughout the 7 month storage period, un-ripened pears behaved fairly similarly despite a wide range in HM (i.e., FF between 54.3 to 42.7N). In general, FF decreased 0.5 to 0.75 N per month; TA declined by ~40%; and, EJ and SSC remained relatively stable. Fruit size, however, significantly increased with each delayed harvest date. Fruit required a minimum of 30 days cold storage to attain ripening capacity (i.e., to soften to ≤17.8 N and develop a buttery, juicy texture), though results differed depending on year and HM. Ripened fruit had significantly lower EJ than non-ripened fruit. After 5 months in RA storage, EJ and FF of ripened fruit increased in both years indicating the loss of ripening capacity. Internal browning was not observed until 6 or 7 months, depending on HM. Respiration and ethylene production rate (EPR) of 'Gem' pears, measured daily for 15 days (at 20°C), progressively increased between 1 and 5 months of RA storage. At 6 months, a change in the pattern of EPR signified the end of the eating-quality, storage life. For both ripened and un-ripened 'Gem' pears, optimal fruit quality was achieved at a HM between 44 and 42N. At a harvest pressure of 44 N, fruit showed no increase in scuffing incidence after processing over a commercial packing line. The maximum RA storage life of 'Gem' pears was 5 months.

'Gem' is a new, fire-blight resistant European pear with several distinguishing extrinsic attributes including a smooth, russet-free fruit finish and red blush (Bell et al., 2014). Productive and precocious fruiting habits, however, predispose 'Gem' to small fruit size and require crop load adjustment (Castagnoli et al., 2011). At harvest, 'Gem' pears are characterized by a crisp, juicy texture – a trait not typically associated with European pears. Crispness, defined as an acoustical sensation during the fracturing of crisp foods when first bitten with the front teeth, differs from firmness, which is described as, the force required to bite completely through a sample placed between the molars (Chauvin et al., 2010; Harker et al., 2002). Firmness, is associated with unripe pears and is preferred less than soft, juicy texture when compared side-by-side (Bruhn et al., 1991; Gallardo et al., 2011; Steyn et al., 2011), though firmness preferences of 'Forelle' pears varied between consumers in the UK and Germany (Crouch et al., 2012). Crispness, on the other hand, was proposed as a trait worthy of future pear breeding attention (Deckers and Schoofs, 2011) and is preferred by a significant

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segment of pear consumers (Jaeger et al., 2003). A preliminary sensory evaluation of 'fresh', un-ripened 'Gem' pears corroborates these findings (Einhorn, unpublished). Selection pressure for crisp, juicy texture has not been widely targeted in the European pear germplasm but has recently been introduced through interspecific hybridization among diverse *Pyrus spp*. (Brewer et al., 2008; Brewer and Palmer, 2011).

Consistent with other European pear cultivars, 'Gem' can also ripen to a soft, buttery and juicy texture when subjected to room temperature for 5 to 7 d. To attain ripening capacity, however, European pears require pre-exposure to low temperatures (i.e., conditioning; Villalobos et al., 2008). This process depends on the generation and perception of ethylene within the fruit. The duration of low temperature conditioning to induce ripening varies according to genotype (Agar et al., 2000; Chen et al., 1982; Sugar and Basile, 2009) and can be affected by harvest maturity (HM) (Chen and Mellenthin, 1981; Elgar et al., 1997; Ma et al., 2000; Sugar and Basile, 2009; Sugar and Einhorn, 2011), storage temperature (Porritt, 1964; Sfakiotakis and Dilley, 1974; Sugar and Basile, 2013; 2014; Sugar and Einhorn, 2011) and ethylene conditioning (Blankenship and Richardson, 1985; Chen et al., 1996; Sugar and Basile, 2013; 2014; Villalobos et al., 2008). Pears that have not received sufficient low temperature conditioning for their maturity level do not soften and ripen properly. Further, ripening capacity can be lost by prolonged storage (Murayama et al., 2002; Xie et al., 2014) resulting in fruit that fail to develop a buttery, juicy texture after exposure to warm temperatures. Inconsistent fruit quality is the principal reason for reduced repeat purchases of pears (Bruhn et al., 1991), placing European pears at a considerable disadvantage in the marketplace relative to other fresh fruits. Hence, developing information characterizing the storage life and ripening behavior of new cultivars is critical to optimizing fruit quality and, subsequently, consumption.

While the dichotomy in texture may increase the marketing versatility of 'Gem', little is known about the postharvest storage life and fruit quality of 'Gem' pears in either the fresh, crisp state or ripened, softened condition. Given the dependence of postharvest fruit quality on physiological maturity, the objectives of the present study were to determine the storage life and describe the postharvest quality and ripening behavior of 'Gem' pears harvested at different maturities.

Materials and Methods

A single row (N:S orientation) of 22 contiguous 7-year-old 'Gem' trees on Old Home × Farmingdale 97 (OH × F 87) rootstock was planted 3.05 × 4.88 m (in row × between row spacing; 672 trees per ha) and trained to a free-standing, central leader architecture at Oregon State University's Mid-Columbia Agricultural Research and Extension Center (MCAREC) in Hood River, Oregon (45.7°N, 121.5°W, elevation 150 m). All trees were lightly thinned at 35 d after full bloom by reducing spur crop load to one to two fruits depending on the fruit density of individual limbs. A randomized complete block design with four replicates was applied to 20 contiguous trees (excluding the end trees of the row) resulting in four blocks of five trees each. In 2011, a roughly equivalent sample of fruit was harvested from each of the five trees comprising a replicate (divided evenly between east and west sides of the row) each week for four weeks (i.e., H1-H4). The first harvest date (H1) coincided with a fruit firmness (FF) value of ~ 54 N; a preliminary indication that fruit was entering the maturity range (Bell et al., 2014). Initial maturity was determined from a 10-fruit sample (per replicate) by measuring FF on opposite sides of each fruit, after removing a ~2.5 cm disc of peel, using a Fruit Texture Analyzer (Güss Manufacturing, Strand, South Africa) fitted with an 8 mm diameter probe. For each harvest, fruit were selected

Table 1. Harvest date, fruit firmness, fruit weight, and fruit size of 'Gem' pears harvested at weekly intervals during 2011 and 2012.

Harvest Maturity	Date	Firmness (N)	Avg. fruit wt. (g)	Avg. fruit size (no. per 20 kg. box)
		2011		
H1	13-Sep	54.7 a[z]	205.1 d	100
H2	19-Sep	49.4 b	215.9 c	90
H3	27-Sep	47.6 b	230.9 b	90
H4	4-Oct	44.1 c	253.3 a	80
Pr>F		*<0.0001*	*<0.0001*	
		2012		
H1	4-Sep	47.3 a	210.6 b	100
H2	13-Sep	42.8 b	222.8 a	90
Pr>F		*0.0002*	*0.0003*	

[z] Data within columns and year with different letters are significantly different by Fisher's Protected LSD test at P=0.05

to represent the 'average' condition of fruit in the orchard. Based on 2011 results and previous, preliminary data indicating optimum post-harvest fruit quality between 48 to 41 N (Einhorn, unpublished), two harvests were performed in 2012, each one week apart (i.e., H1 and H2). Identical trees were utilized in 2012 as in 2011 and fruit were thinned at 38 d after full bloom to achieve similar crop loads as in 2011. The maturity index (FF) and fruit size for all harvest dates and years are provided in Table 1.

Each week, 150 fruit were harvested from each of four replicate groups of trees. Ten fruit per replicate were used to determine fruit quality attributes at harvest. The remaining 140 fruit per replicate were placed in poly-lined, wooden lugs in a regular air (RA) cold storage room maintained at -1 °C and ~95% RH. Each year, RA temperature was monitored twice daily throughout the entire storage period. Thirty days after each harvest date, a 20-fruit sample per replicate was removed from RA. Ten fruit per replicate were evaluated for FF, extractable juice (EJ), soluble solids concentration (SSC), and titratable acidity (TA) after 4 hr at room temperature. After determining FF (described above), two slices per fruit (from opposite sides) of 10 fruit were peeled and juiced (Juice Extractor 6001C, Waring Products, New Harford, Conn.). Using a pipette, 500 µL of juice was pipetted onto a digital refractometer (Palette series, PR-101α, Atago USA, Inc., Kirkland, WA) to determine SSC. TA, as malic acid equivalents, was determined using 10 mL of juice + 10 mL of de-ionized water and titrated with 0.1 N sodium hydroxide to an endpoint pH of 8.1 using a titrator fitted with an automated sampler (DL15 and Rondolino, Mettler-Toledo Inc., Zurich, Switzerland). A separate juice sample was collected over 30 s from 100 g (± 0.25 g) of fresh fruit (~ 10 g slice taken from each of 10 fruits) and transferred to a graduated cylinder for determining EJ. EJ is an objective measure that correlated well with texture of European pears (Chen and Borgic, 1985; Xie et al., 2014). All fruit were individually weighed and averaged across all sampling dates to estimate average fruit weight for each harvest date. Insignificant moisture loss from fruit in poly-lined wooden lugs was assumed to occur throughout the 7 month storage period based on previous experiments under identical RA conditions (Wang and Sugar, 2013); thus, fruit weight represented mass at harvest. The remaining 10 fruit per replicate were placed in 20 °C (± 1 °C) for 7 d. On the seventh day, FF, EJ, SSC and TA were measured as described above to evaluate ripeness . A FF value of 17.8 N was used to indicate ripeness to the onset of a buttery, juicy texture (Sugar and Einhorn, 2011). This sampling regime was repeated monthly until fruit quality was compromised by the presence of storage disorders (i.e., 7 and 6 consecutive months in 2011 and 2012, respectively). An identical protocol was followed in 2012, with the exception that fruit of both harvest dates were ripened immediately after harvest.

In 2012, ethylene production rate (EPR) and respiration rate (Rs) of fruit were determined daily over a 15 d period each month for the entire 6-month postharvest period. Briefly, five fruit per replicate were placed in a 3.8-L airtight jar immediately after removal from RA and maintained at 20 °C. Gas samples were withdrawn through a septum using a 1-mL gas-tight syringe after 1 hr. Jars were then opened for a 24-hr period (air temperature was maintained at 20 °C). Fruit were gently removed from jars and the jars were flushed with air to ensure that no residual CO_2 or ethylene existed prior to replacing the fruit and resealing the jars for the subsequent 1 hr incubation period. This procedure was repeated daily over a 15 d period. The headspace gas was injected into a GC (GC-8A; Shimadzu, Kyoto, Japan) to quantify ethylene. Nitrogen was used as the carrier gas at a flow rate of 50 mL/min. The injector and detector port temperatures were 90 and 140 °C, respectively. An external standard of ethylene (1.0 $\mu L \cdot L^{-1}$) was used for calibration and EPR was expressed as $\mu L \cdot kg^{-1} \cdot hr^{-1}$. Headspace CO_2 concentration was measured using a CO_2 analyzer (Model 900161; Bridge Analyzers Inc., Alameda, CA). Fruit Rs was expressed as mL of $CO_2 \cdot kg^{-1} \cdot hr^{-1}$.

In 2013, ~ 45 kg of fruit was harvested from each 5-tree replicate when FF reached ~44 N, which was between the HM of H4 fruit of 2011 and H2 fruit of 2012. Fruit were delivered immediately to a commercial packing house (Duckwall Fruit, Hood River, OR) and processed over a 'Comice' packing line (i.e., belts were employed to cover brushes given the higher sensitivity of 'Comice' pears to surface injury compared to other cultivars) and commercially packed into 20-kg boxes. Two, 20-kg boxes per replicate were transported to MCAREC and placed in RA storage (-1 °C, ~95% RH). Boxes were removed from RA storage after 4 months. Half of the fruit in each box was evaluated 4 hr upon removal from RA for fruit quality attributes (FF, SSC and TA) and surface blemishes. An objective scale was developed to assess surface blemishes that comprised five discrete classes: Clear, [no visible surface blemishes]; Very Slight, [0.5 cm^2 or less fruit surface area blemished]; Slight, [0.6-1.0 cm^2]; Moderate, [1.1-3 cm^2]; and, Severe, [> 3 cm^2]. A weighted value between 1 and 5 was assigned to each class (i.e., Clear=1, Severe=5). The number of fruit in each class were multiplied by their respective severity scores, summed and divided by the number of fruit evaluated. A scuffing incidence was calculated as the sum of fruit in Slight, Moderate and Severe classes divided by the sum of fruit evaluated. The scuffing incidence is based on thresholds for surface blemishes for packing grades and was developed in collaboration with commercial packing house representatives. The remaining ~ 10 kg of fruit per box was ripened and evaluated as outlined above after 7 d at 20 °C.

Statistical analyses were performed using the SAS system software (SAS 9.3, SAS Institute, Cary, N.C.). Treatment means were compared using analysis of variance (ANOVA) with PROC GLM and significance was tested at $P \leq 0.05$. Mean separation was determined by Fisher's protected least significant difference test (LSD). Data shown in Figs. 1 and 2 are means of 4 replicates ± se.

Results and Discussion

In 2011, the first harvest commenced when fruit softened to <55 N. At this firmness, 'Gem' pears ripened to acceptable fruit quality following several months of cold storage (Bell et al., 2014). Subsequent harvests occurred at ~1 week intervals until FF softened to levels perceived to represent the end of the acceptable maturity range (44 N). Over this 21 d harvest period, a 22% increase in fruit wt. (Table 1) was well-described by a linear function (fruit wt. = 2.2547d + 203.18, $R^2 = 0.9804$). Delayed harvesting, therefore, is a plausible strategy to increase fruit size of small-fruited European pear genotypes such as 'Gem' (Bell et al., 2014), so long as the effects on postharvest fruit quality and storage life are determined. Although fruit of a given FF were smaller in 2012 compared to 2011, a roughly equivalent increase in the rate of weight gain between harvest dates was observed both years (Table 1). The absolute difference in fruit size between years was attributed to vastly different environmental conditions, since crop load was similar in 2011 compared to 2012.

In both years, the presence of storage disorders [primarily internal browning (IB)] limited the maximum storage life of 'Gem' to 6 months, notwithstanding H1 fruit of 2011 (i.e., harvest FF > 50 N), which remained free of IB through 7 months. Over the entire storage period FF of fruit evaluated within 4 hr of removal from RA declined linearly ~ 0.75 N per month irrespective of HM or year (Fig. 1A and B). A monthly, informal sensory evaluation of 'Gem' pears after removal from RA, but before ripening, indicated that fruit maintained both firm and crisp properties throughout the entire postharvest period, including the final, 6-month analysis of H4 fruit (i.e., 40.2 N). Although the Güss penetrometer is primarily used to quantify FF, it also produced relatively high correlation coefficients for crispness when compared to alternative instruments to assess textural properties of apples and pears (Chauvin et al., 2010). Since crispness is the principle attribute distinguishing 'Gem' pear from most un-ripened European pear cultivars, and based on the similar postharvest performance of 2011 H2, H3 and H4 fruit (Fig. 1), a narrower and more advanced range of maturity was targeted for 2012 harvests (47.1 to 42.7 N). These FF levels are considerably lower than those associated with the harvest of all other major European pear cultivars produced in the US, potentially predisposing 'Gem' to higher levels of damage during commercial postharvest procedures. 'D'Anjou' pears showed minimal blemishes following commercial packing operations when FF values exceeded 35.3 N (Mellenthin and Chen, 1981); however, the threshold FF for injury would be expected to differ based on biochemical, anatomical and physiological features of the epidermal and cortex tissues of different genotypes. 'Gem' pears harvested at ~44 N and immediately processed over a commercial packing line, including packaging into 20-kg boxes, showed a slight, significant increase in surface blemishes (i.e., scuffing severity) but remained at relatively low levels that did not translate to a higher incidence in scuffing compared to control fruit (Table 2). Importantly, scuffing incidence did not increase after fruit were ripened to FF of < 15 N (Table 2); however, we emphasize that 'Gem' pears were not exposed to brushes during travel through the packing line, a practice commonly utilized for 'Comice' pears, based on a presumption that their smooth finish would predispose them to greater injury.

Ripening capacity of H2, H3 and H4 pears in 2011 and H2 pears in 2012 was achieved by 30 d RA storage after provision of a 7 d ripening period (Fig. 1A and B). In 2011, the more mature fruit of H1 required between 30 and 60 d to soften below 17.8 N. It is unclear why H1 fruit in 2012 did not attain ripening capacity after 1 month of RA (Fig. 1B) despite having an equivalent harvest FF as H3 fruit of 2011, which softened to 6.2 N after 30 d. The duration of chill required to attain ripening capacity at a given HM was similar over multiple years for 'd'Anjou' (Sugar and Einhorn, 2011), 'Comice' and 'Bosc' (Sugar and Basile, 2009), and 'Packham's

Table 2. The effect of commercial packing operations on scuffing severity and incidence of un-ripe and ripened 'Gem' pears harvested at FF of ~44 N and immediately processed over a commercial packing line and packaged into 20-kg boxes. Fruit were stored in regular air cold storage (-1 °C, >95% RH) for 4 months prior to evaluation. Unripe pears were evaluated within 4 hr of removal from cold storage. Ripened pears were exposed to 20 °C for 7 consecutive days prior to evaluation. Fruit quality attributes at each evaluation are provided: FF, fruit firmness; SSC, soluble solids concentration; and, TA, titratable acidity.

	Scuffing severity[z] (1 to 5 scale)		Suffing incidence[y] (%)		FF (N)		SSC (%)		TA (%)	
Treatment	Unripened	Ripened	Unripened	Ripened	Unripened	Ripened	Unripened	Ripened	Unripened	Ripened
Control Packing	1.04	1.09	0	0	41.8	14.7	14.2	14.5	0.36	0.25
line	1.08	1.15	0	1	43.0	14.2	14.3	14.6	0.28	0.26
Pr>F	0.3665	0.0098	- - -	0.3739	0.4435	0.4981	0.7951	0.3739	0.192	0.606

[z] Fruit were classified into 5 classes: Clear, no visible surface blemishes; Very Slight, 0.5 cm^2 or less fruit surface area blemished; Slight, 0.6-1.0 cm^2; Moderate, 1.1-3 cm^2; and, Severe, > 3cm^2. A weighted value between 1 and 5 was assigned to each class (i.e., Clear=1, Severe=5). The sum of the number of fruit in each class multiplied by their respective severity scores was divided by the number of fruit evaluated.

[y] Scuffing incidence was calculated as the sum of fruit in Slight, Moderate and Severe classes divided by the sum of fruit evaluated.

Triumph' and 'Gebhard Red d'Anjou' (Sugar and Basile, 2014). Interestingly, the well-established 60-d chill requirement to induce ripening of 'd'Anjou' pears entering maturity (i.e., ~65 N) in Hood River, OR (Chen and Mellenthin, 1981; Sugar and Einhorn, 2011) was extended to 75 d in 2012 (Wang, unpublished). Varied chill requirements for inducing ripening were also reported for 'd'Anjou' pears in Medford, OR for different production years (Sugar and Basile, 2013). The reasons for this disparity are unclear. To elucidate whether 'Gem' pears could ripen in the absence of low temperature conditioning, we subjected pears to 7 d of 20 °C immediately after each of the two 2012 harvest dates; results confirmed that 'Gem' does indeed require low temperature conditioning to soften and attain a buttery, juicy texture (Fig. 1B).

After 5 months of RA storage, 'Gem' pears began to lose their capacity to ripen as indicated by increasingly higher FF of ripened fruit (i.e., FF ≥18 N at 6 months; Fig. 1A and B). Importantly, this phenomenon was consistent between years and was not affected by HM. Concomitantly, EJ increased with cumulative storage duration for ripened fruit after 4 to 5 months, albeit non-significantly (Fig. 1C and D). Biochemical changes in cell wall polysaccharides were associated with higher FF (Chen et al., 1983; Murayama et al., 2002) and EJ (Chen et al., 1983) following ripening of pears subjected to prolonged storage periods (Chen and Borgic, 1985; Murayama et al., 2002; Wang et al., 1985); thus, we propose that the optimal RA storage life of 'Gem' is 5 months.

Throughout the duration of RA storage, there was no detectable change in fruit SSC, irrespective of HM or ripening treatment (Fig. 1E and F). A postharvest increase in SSC, as a function of starch hydrolysis, is rarely observed in European pears given the negligible starch content of cortex tissue at harvest. This, in combination with respiratory preference for organic acids, results in stable SSC throughout the postharvest life of European pears. Titratable acidity, on the other hand, declined by ~ 40% over the 6 month storage period, irrespective of HM or year (Fig. 1G and H). Interestingly, the pattern of TA loss differed between years. Reasons for this are unclear since equivalent storage temperatures (monitored daily) were maintained between years, but one possibility is that fruit of the same HM were physiologically more advanced in 2011 than

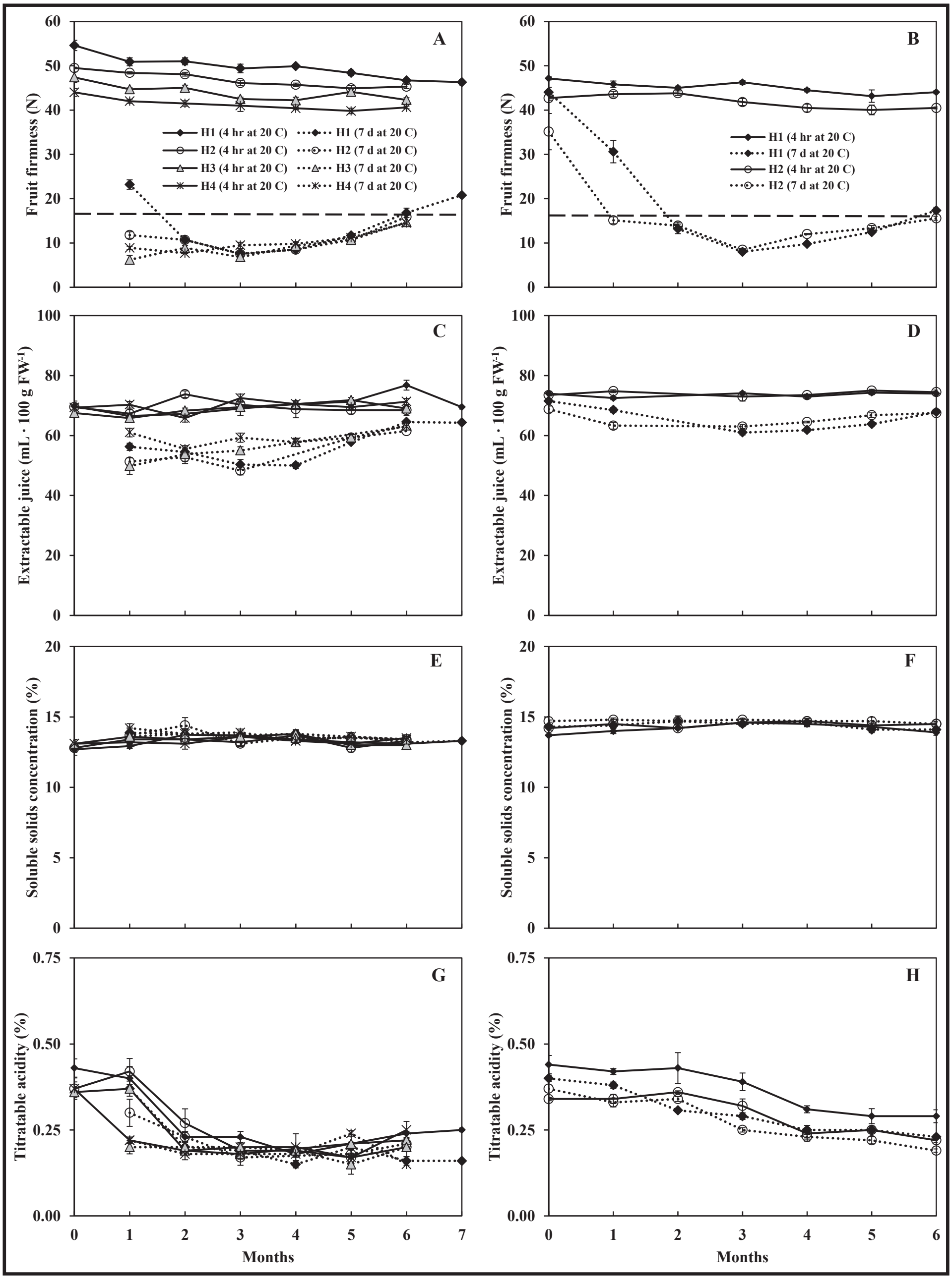

Figure 1. The effect of harvest maturity in 2011(H1-H4) and 2012 (H1-H2) on fruit firmness (FF) (A, B), extractable juice (EJ) (C, D), soluble solids concentration (SSC) (E, F), and titratable acidity (TA) (G, H) each month at 4 hr from removal from regular air cold storage (-1°C) (solid lines) and after ripening for 7 days at 20°C (dotted lines). The hashed line in panels A and B signifies the maximum FF required for fruit to attain ripening capacity (i.e., 17.8 N). Data are means of 4 replicates ±se.

2012. The developmental period between full bloom and harvest for fruit harvested at ~ 47 N was 148 and 134 d for H3 and H1 fruit of 2011 and 2012, respectively. This 14 d developmental difference may also help to explain the disparate ripening behavior between these treatments after 30 d of RA storage.

Fruit respiration followed a climacteric pattern between 2 and 6 months of storage, typically peaking on day 3 to 4, irrespective of HM (Fig. 2B and D). A slightly higher, basal level of Rs was detected for the more mature H2 fruit after 1 month RA storage (i.e., between days 3 and 13). EPR was also slightly, albeit significantly, higher for H2 fruit compared to H1 fruit after 1 month RA storage (Fig. 2A and C). Higher EPR and Rs likely explain the differences in the ripening behavior of H1 and H2 fruit after 30 d of storage (Fig. 1A and B). Between 2 and 4 months, the levels and patterns of Rs and EPR were similar for H1 and H2 fruit. The EPR peak occurred earlier (i.e., from 12 to 5 d) as time in storage increased, until 6 months when a rapid and steady decline was observed after day 1. Such a pattern indicates the loss of ripening capacity (Ma and Chen, 2003; Wang and Sugar, 2013) and corroborates the increasing FF and EJ observed for fruit stored for 6 months (Fig. 1B). Internal ethylene production of fruit stimulates synthesis of flavor compounds and accelerates pear ripening (Villalobos et al., 2008). In fact, 'd'Anjou' pears treated with exogenous ethylene ripened to a higher eating quality than fruit not conditioned with ethylene (Chen et al., 1996; Sugar

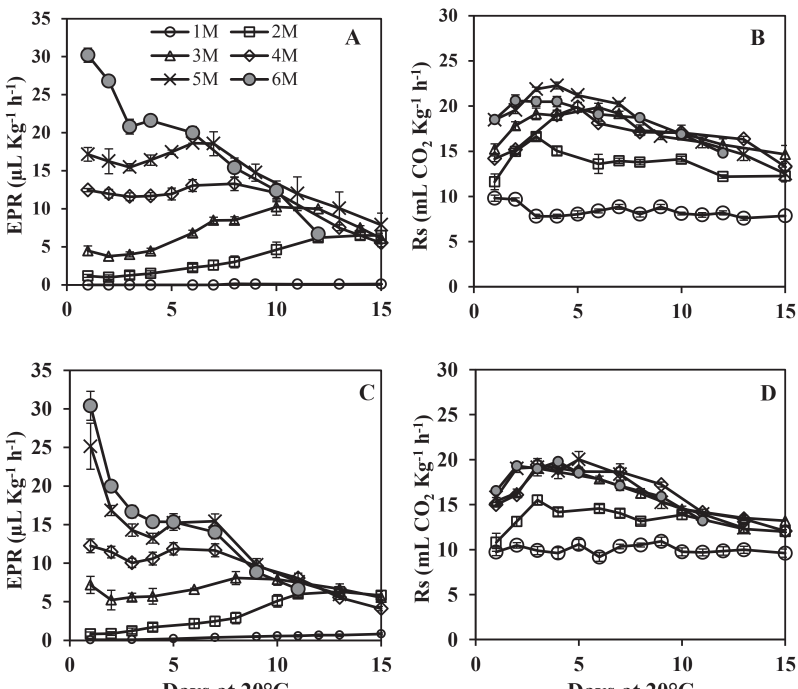

Figure 2. The effect of 2012 harvest maturity on daily ethylene production rate (EPR; A,C) and respiration rate (Rs; B, D) of 'Gem' pears each month (M) after removal from regular air cold storage (-1°C). Fruit were harvested 10 days apart based on fruit firmness (FF): Harvest 1 (H1) FF was 47.1 N (A,B); and, Harvest 2 (H2) FF was 42.7 N (C, D). Data are means of 4 replicates ±se.

and Einhorn, 2012). Within 4 hr from RA storage, un-ripened 'Gem' pears developed exceptional flavor when provided ≥3 months of cold storage, compared to fruit stored for 0, 1, or 2 months (Einhorn, unpublished). The fact that pears stored for 3 to 4 months RA had an EPR roughly 5 to 10-fold greater than pears stored <2 months supports this observation (Fig. 2A and B). Enhancing the flavor profile of 'Gem', while maintaining the cultivar's distinguishing, crisp attributes, warrants future research attention.

In conclusion, when harvested between 42 and 44 N, 'Gem' pears required 30 d of RA storage to attain ripening capacity. At these harvest pressures, fruit withstood commercial packing operations without an increase in the incidence of scuffing. Fruit quality between 1 and 5 months of RA storage was not greatly impacted by HM between 54.7 to 42.7N; however, fruit size was markedly improved with delayed harvests. A loss of ripening capacity with prolonged RA storage limited the postharvest storage life of 'Gem' pears to 5 months.

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