QUALITY OF 'GALA' APPLES AS INFLUENCED BY HARVEST MATURITY, STORAGE ATMOSPHERE AND CONCOMITANT STORAGE WITH 'BARTLETT' PEARS[1]

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ABSTRACT

Controlled atmosphere (CA) storage for 45 or 90 days following harvest reduced quality losses for both 'Gala' apples and 'Bartlett' pears compared with fruit from regular atmosphere (RA) storage. Fruit stored in CA were firmer, had higher acidity and less color change than fruit from RA storage. Apples and pears stored together in CA maintained good quality and compared favorably with apples or pears stored separately. There was no difference in fruit quality between fruit stored at 1% O_2 and 1% CO_2 compared with fruit stored in 2% O_2 and 3% CO_2. Fruit harvested at a more advanced stage of maturity deteriorated more quickly in storage than earlier harvested fruit. A combination of 45 days in CA followed by 30 days RA resulted in apples that were superior in quality to apples stored for 75 days in RA alone.

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INTRODUCTION

'Gala' is an apple cultivar growing in popularity in Washington State with about 2,680 ha in production (WASS 1993). As volume has increased, questions have been raised concerning proper harvest maturity for storage. Because the storage-life in regular atmosphere (RA) is relatively short (Drake 1991), particular attention has been given to storage in controlled atmosphere (CA). Because of the early August harvest many storage facilities cannot be filled with Gala apples alone. Thus CA storage of Gala apples with other cultivars or species is desirable.

Washington grown 'Bartlett' pears also mature during early August and have a storage-life similar to Gala apples. Bartlett pears can be certified from CA only after 45 days in storage (WAC 1989). This length of storage would also meet the CA certification requirement for Gala (WAC 1994). Meheriuk (1993) reported that the O_2 and CO_2 requirements for CA storage of Gala apples (1 to 2.5% O_2 and 1 to 5% CO_2) and Bartlett pears (1 to 3% O_2 and 0.5 to 3% CO_2) were similar for O_2 level but not for CO_2. Some workers have reported that levels of CO_2 above 0.5 resulted in physiological disorders in Bartlett pears (Richardson and Meheriuk 1989). In contrast, others have shown higher CO_2 enhances storage-life (Claypool 1973; Ke *et al.* 1990). Bender (1989) found that Gala apples responded favorably to CA storage when the O_2 level was kept below 2%. Recent research (Walsh *et al.* 1991; Boylston and Kupferman 1992) indicated that storage quality of Gala apples was directly related to harvest maturity. Plotto (1992) suggested that ground color may be an acceptable maturity indictor for Gala apples.

This study was conducted to determine (1) the response of Gala apples harvested at different maturities to CA storage and (2) to examine the possibility of storing Bartlett pears with Gala apples.

MATERIALS AND METHODS

This study was conducted over two crop seasons (1993 and 1994) using Gala apples and Bartlett pears. Apples were harvested both years on three occasions at 7-day intervals from a commercial orchard located in Vantage, WA. Apple maturity at each harvest was based on background color (harvest 1 green; harvest 2 white; harvest 3 yellow). Nine hundred apples of uniform size and color were obtained at each harvest, 300 from each of three locations within the orchard. After each harvest, each group of apples was divided into five lots of 60 apples each (three replications of 20 fruit) and immediately placed in storage with or without Bartlett pears. At the time of each apple harvest, freshly harvested Bartlett pears (900) were obtained from a commercial packing house and divided as described above for apples.

The individual lots of apples and pears were placed in either regular atmosphere (RA) or (CA) storage at 1C. Atmospheres in the CA chambers (0.14m^3) were either 1% O_2 and 1% CO_2 or 2% O_2 and 3% CO_2 and were established in less than 12 h. Atmospheres were maintained to ± 0.1% using a computer control system (Technical Consulting Service, Chelan, WA). Nitrogen was supplied by a membrane separation system. After 45 and 90 days in storage, apples and pears were removed to assess quality. Another lot of apples and pears was removed from CA after 45 days and held an additional 30 days in RA storage.

Twenty apples and pears from each harvest, storage type and replication were used for quality analysis after each storage period (0 days, 45 days RA or CA, 45 days CA plus 30 days RA, and 90 days RA or CA). Ten apples and/or pears from each treatment combinations were examined immediately upon removal from storage. The remaining 10 apples or pears from each treatment combination were examined after a 7-day ripening period at 20C. Fruit quality was evaluated by measuring firmness, external and internal color, soluble solids content (SSC), and titratable acidity. Each fruit was also examined visually for defects.

Firmness was determined using TA-XT2 Texture Analysis (Texture Technologies Corp., Scarsdale, NY) equipped with a 11.1mm (apple) or 7.8mm (pear) probe. External and internal fruit color were determined with a CR300 Minolta Chromameter (Osaka, Japan) using the Hunter L, a, b system and calculated hue values (Hunter and Harold 1987). Three values for external color were determined around the circumference of each fruit. Internal color was measured by cutting each fruit in half horizontally and immediately taking a reading on the exposed flesh surface of the calyx end. The average value for 10 fruit was reported for all color analyses. Titratable acidity was determined with a Radiometer titrator (Model TTT85 Radiometer, Copenhagen).

Juice prepared from fruit samples was pooled and titrated to pH 8.2 with 0.1N NaOH; values were expressed as percent malic acid. SSC of the extracted juice was determined with an Abbe-type refractometer calibrated @ 20C. Disorders were evaluated by visual assessment and expressed as the percentage of fruit affected. Analysis of variance was determined by MSTAT (1988) using a factorial design with storage type and storage time as split plots on harvest date with years combined. Based on a significant F test, means were separated by Tukey's honestly significant difference test (HSDT).

RESULTS AND DISCUSSION

Gala apples harvested over a three week period differed in maturity (Table 1). Firmness decreased an average of 4 to 4.5 N with each sequential harvest. This 4N

TABLE 1.
MATURITY INDICES OF GALA APPLES AND BARTLETT PEARS FROM 3 SEQUENTIAL HARVEST DATES

	Harvest	Firmness	Weight	Starch	Hunter Color		
		(N)	(g)	(1-5)[z/]	a	b	Hue
Gala	I	80.9 a[y/]	185 a	3.1 b	27.1 a	17.8 b	34 NS
	II	76.8 b	183 a	3.3 b	26.0 a	19.8 ab	38
	III	70.0 c	186 a	4.4 a	27.0 a	21.1 a	38
Bartlett	I	71.3 a	202 a	2.2 b	-9.2 b	28.6 a	107 a
	II	75.7 a	150 b	1.9 b	-8.0 a	28.2 a	105 b
	III	74.4 a	189 a	4.0 a	-8.4 ab	26.8 b	107 a

[y/] Means within cultivar not followed by a common letter are significantly different (P≥0.05)Tukey's HSDT.
[z/] Starch conversion sacle of 1 to 5 (1 = no conversion; 5 = complete conversion).

loss in firmness is significant (Olsen 1985) and may have a detrimental influence on the quality of fruit from CA. Depletion of the starch content was apparent, particularly after the second harvest. Uniformly red apples (Hunter a values) were picked over the entire harvest time but background color became increasingly yellow (Hunter b values). No increase in size (wt) due to delayed harvest was evident.

Bartlett maturity at all harvests was similar (Table 1). Starch content was constant for the first two harvests, but decreased significantly by the third harvest.

Harvest time and storage atmosphere influenced the quality of Gala apples (Table 2). Regardless of maturity at harvest, apples stored in CA (1% O_2) were about 13% firmer than apples stored in RA. This difference in firmness between the two types of storage was consistent for all three harvest periods. RA apples from harvest III had firmness values (51.7N) that would not meet the Washington State export standard (53.4N) for 'Delicious' apples (WAC 1990). Firmness values for CA apples from harvest III were less than those for CA apples from harvests I and II. Firmness values for CA apples from harvest III were less than those for RA apples from harvest I and similar to those for RA apples from harvest II. Nonetheless, the firmness of apples after either type of storage (RA or CA) was least at the last harvest.

As length of storage increased from 45 to 90 days, apples in RA lost firmness whereas firmness of apples in CA did not change. There was an 18% difference in firmness for apples from the two storage conditions. After an 8-day ripening period, apples from CA were still 17% firmer than RA apples prior to the ripening.

The acid content of Gala apples from the first two harvests was similar. Only a slightly higher acid retention was noted for apples stored in CA compared with apples stored in RA (Table 2). Acid content of the apples from harvest III was lower than that from the first two harvests. There was no difference in acid content between the two storage conditions (CA or RA). A loss of acid for Gala apples was evident from 45 to 90 days in RA, but not for those in CA. During an 8 day ripening period apples from RA lost more acid than those from CA. This loss in acid might influence consumer acceptance because consumers generally prefer apples of higher acid content (Boylston *et al.* 1994).

Although external color changed at the last harvest (III), neither length nor type of storage had any influence (Table 2). Apples from the harvest III had distinctly less red and more yellow color (higher hue) than apples from the other two harvests. Apples ripened for eight days were lighter in color with less red and more yellow color. Internal color was not influenced by harvest or storage atmosphere. Increased storage time and advanced ripening did result in a yellower and less green flesh color (data not shown) which, though slight, is detectable by the human eye (Hunter and Harold 1987).

TABLE 2.
INFLUENCE OF HARVEST, STORAGE ATMOSPHERE, STORAGE TIME AND RIPENING TIME ON THE FIRMNESS, ACID CONTENT, AND EXTERNAL COLOR OF GALA APPLES STORED AT 1C

Harvest × Atmosphere		Firmness (N)	Titratable Acidity (% Malic)	Color (Hue)
I	RA	62.0 c[z]	0.38 b	36.9 c
	CA[y]	70.2 a	0.40 a	38.4 bc
II	RA	60.0 cd	0.38 b	38.1 bc
	CA	65.7 b	0.40 a	39.8 bc
III	RA	51.7 e	0.30 c	43.3 a
	CA	59.1 d	0.31 c	41.0 ab
Atmosphere × Storage				
RA	45 days	60.4 b	0.37 a	39.2 a
	90	55.2 c	0.33 b	39.7 a
CA	45	65.2 a	0.37 a	39.4 a
	90	67.7 a	0.37 a	40.1 a
Atmosphere × ripe				
RA	0 days	63.3 b	0.38 a	36.6 a
	8	52.5 c	0.33 c	42.3 a
CA	0	68.5 a	0.38 a	37.4 a
	8	61.5 b	0.36 b	42.0 b

[z] Mean separation within groups by Tukey's HSDT ($P \geq 0.05$).
[y] Controlled atmosphere (1% O_2 and 1% CO_2).

Gala apples stored with Bartlett pears had quality attributes similar to apples stored separately (Table 3). After 90 days, apples from CA were firmer than apples in RA, both immediately after storage and after a 7-day ripening period. Apples stored in CA alone or with pears lost about 6N in firmness after ripening. After 90 days of CA storage, apples stored alone or with pears maintained acceptable firmness (60N) following ripening. Mean firmness of apples from CA plus seven days of ripening was higher than that for RA apples before ripening. In addition, apples from RA storage lost more acid during the ripening period than apples from either CA treatment. No other quality changes were evident for apples stored with pears over the 90 day period. Apples stored separately or with pears maintained good condition at either 1% O_2 and 1% CO_2 or 2% O_2 and 3% CO_2.

TABLE 3.
FIRMNESS AND ACID CONTENT OF GALA APPLES STORED ALONE AND WITH BARTLETT PEARS FOR 90 DAYS

Atmosphere	Firmness (N)	Titratable Acidity (% Malic)
RA	55.3 b[z]	0.33 b
CA 1[y]	64.2 a	0.37 a
CA 2[x]	63.6 a	0.37 a
CA 3[v]	64.7 a	0.37 a

[z] Mean separation by Tukey's HSDT ($P \geq 0.05$).
[y] Gala apples stored alone (1% O_2 and 1% CO_2).
[x] Gala apples with Bartlett pears (1% O_2 and 1% CO_2).
[v] Gala apples with Bartlett pears (2% O_2 and 3% CO_2).

After 45 days of CA storage Bartlett pears stored separately or with apples were in better condition than pears from RA storage (Table 4). Pears stored with Gala apples in CA were firmer than pears stored separately in RA storage. Firmness of pears stored separately in CA was comparable to pears from RA and pears in CA stored with apples. After ripening, firmness values were similar regardless of storage regime. Pears from CA storage were greener (higher hue values) than pears from RA storage both before and after ripening. A similar pattern was noted for internal flesh color. Acid content of pears from CA storage was greater than that of pears from RA storage. After 90 days, pears in RA storage were unacceptable whereas pears from CA storage maintained good commercial quality. After 90 days of CA, pears stored separately or with apples had good firmness values and high acid content regardless of CA storage regime.

There were some external and internal color differences between the different CA storage atmospheres. Pears stored with apples at 1% O_2 and 1% CO_2 were externally greener immediately after storage than pears alone at 1% O_2 and 1% CO_2 or with apples at 2% O_2 and 3% CO_2. Internal color differences of pears between the different CA storage conditions were small and would not be expected to be noticed by consumers. Pears stored well in CA for 90 days' either with or without apples.

Better apple quality was achieved after 75 days storage in a combined CA/RA regime than fruit from RA storage alone (Table 5). Apples in CA/RA storage were 8N firmer than apples in RA alone. This is important because of the State's requirement that certain apples cultivars such as Delicious meet a minimum firm-

TABLE 4.
FIRMNESS, COLOR AND ACID CONTENT OF BARTLETT PEARS STORED ALONE OR WITH GALA APPLES

Atmosphere x Ripe (days)		Firmness (N)	Color External Hue	Color Internal Hue	Titrat. Acidity % Malic
45 days Storage					
RA	0	64.2 b[z]	97.1 b	83.4 b	0.34 b
	7	8.3 c	78.8 d		
CA 1[y]	0	69.5 ab	102.8 a	86.8 a	.38 a
	7	8.7 c	84.1 c		
CA 2[x]	0	71.4 a	103.9 a	87.6 a	.38 a
	7	8.1 c	83.5 c		
CA 3[v]	0	70.7 a	102.6 a	86.9 a	.39 a
	7	8.9 c	82.6 c		
90 days Storage					
CA 1[y]	0	54.5 ns	85.6 b	82.5 ab	0.34 ns
	7	14.5			.32
CA 2[x]	0	53.2	88.0 a	83.6 a	.33
	7	15.1			.34
CA 3[v]	0	53.8	84.6 b	81.4 b	.33
	7	14.3			.32

[z] Mean separation in storage groups by Tukey's HSDT($P \geq 0.05$).
[y] Bartlett pears stored alone(2% O_2 and 3% CO_2).
[x] Bartlett pears stored with Gala apples (1% O_2 and 1% CO_2).
[v] Bartlett pears stored with Gala apples (2% O_2 and 3% CO_2).

ness standard of 53.4N. Apples stored for 75 days in RA barely exceeded (56N) the firmness requirement, whereas apples from CA/RA storage maintained a firmness of 64.0N. In addition to enhanced firmness, apples from the CA/RA had higher acid content than apples from RA alone. No external color differences were noted in apples from the two storage regimes. Internal color of apples from RA storage, however, was more yellow with less green (smaller hue values) than those from CA/RA storage.

Pears did not respond to CA/RA storage in the same manner as apples (Table 5). Although initially 10% firmer than pears from the combination storage, pears

from RA were not firmer after ripening. Pears from CA/RA storage were initially greener with less yellow background color than pears from RA storage alone, but after 7 days of ripening there were no color differences.

TABLE 5.
FIRMNESS, ACID, AND COLOR CONTENT OF GALA APPLES AND BARTLETT PEARS AFTER 45 DAYS OF CA PLUS 30 DAYS OF RA STORAGE

Gala Atmosphere		Firmness (N)	Titrat. Acidity (% Malic)	Color External Hue	Color Internal Hue
Gala					
RA		56.0 b[z]	0.34	40.5 a	92.0 b
CA/RA[y]		64.0 a	0.36	39.8 b	94.5 a
Bartlett					
Atmosphere x Ripe (days)					
RA	0	73.5 a[x]	0.28 ab	95.7 b	86.8 a
	8	12.5 c	0.26 b	84.6 c	83.7 a
CA/RA[w]	0	66.7 b	0.32 a	99.7 a	88.2 a
	8	13.5 c	0.29 ab	86.5 c	85.1 a

[z]Mean separation by analysis of variance ($P \geq 0.05$).
[y]Forty-five days of CA (1% O_2 and 1% CO_2) storage followed by thirty days RA storage all at 1C.
[x]Mean separation by Tukey's HSDT ($P \geq 0.05$).
[w]Forty-five days of CA (2% O_2 and 3% CO_2) storage followed by thirty days RA storage all at 1C.

CONCLUSIONS

Presently, most Gala apples destined for early markets (< 90 days) are stored and shipped in RA. Apples respond to CA at either 1% O_2 and 1% CO_2 or 2% O_2 and 3% CO_2 for periods up to 90 days with no loss of quality. Apples that receive 45 days of CA before RA transit should arrive in better condition than those stored in RA alone. Based on background color, apples should be harvested at the green or white stage for best quality maintenance during storage.

Manipulation of the storage regime had much less influence on the quality of pears. After 75 days CA/RA storage offered little advantage over RA alone. Pears stored in CA at either 1% O_2 and 1% or CO_2 or 2% and 3% CO_2 for up to 90 days maintained excellent fruit quality. In general Gala apples and Bartlett pears harvested at the same time of year stored very well together in CA for 90 days of storage with no adverse effects on fruit quality.

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