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Response of Three Strains of 'Gala' Apples to High Carbon Dioxide Prior to Controlled Atmosphere Storage

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Abstract

The postharvest fruit quality of three strains ('Royal Gala,' 'Imperial Gala' and 'Crimson Gala') of apples was evaluated over two or three storage seasons. To determine the influence of carbon dioxide treatment on storage quality, apples were stored in normal controlled atmosphere (1% O_2 & 1% CO_2), or treated with 12% CO_2 for 7 or 14 days prior to normal CA and evaluated after 90 or 150 days of storage. The use of 12% CO_2 prior to storage helped to maintain firmness of 'Royal Gala' apples in 1 of 3 seasons. Firmness of 'Imperial Gala' and 'Crimson Gala' apples was not influenced by high CO_2 treatment, regardless of storage season. Other quality factors (color, soluble solids, acidity and carbohydrates) were not influenced to the extent that high CO_2would be a viable option for the quality enhancement of 'Gala' apples during storage, regardless of strain. Use of normal CA maintained 'Gala' apple quality for 150 days of storage. Harvest date had a major influence on 'Gala' apple quality. A delay of one week reduced firmness and acidity, but enhanced color and content of sucrose, glucose and fructose in 'Royal Gala,' 'Imperial Gala' and 'Crimson Gala' apples.

Introduction

'Gala' is an apple cultivar growing rapidly in popularity in the state of Washington and in other apple growing regions of the world (5). New strains of this cultivar are being introduced. However, 'Gala' apples are not well adapted to long term controlled atmosphere (CA) storage because they rapidly lose firmness and aromatic constituents of flavor during storage (8). Increases in production have stimulated interest in holding 'Gala' apples in storage for longer periods of time while retaining quality.

'Gala' apples have been held in CA storage at 2% O_2 and 3% CO_2 for periods of 90 days with little or no quality loss (9). Meheriuk (14) identified the optimum $O_2$and CO_2 concentration ranges for CA storage of 'Gala' apples to be 1 to 2.5% O_2 and 1 to 5% CO_2. Bender (2) found that 'Gala' apples respond favorably to CA storage when the O_2 level was kept below 2%. Other research (3, 11, 18) has indicated that quality of 'Gala' apples following storage was directly related to harvest maturity.

Couey and Olsen (7) reported that exposure of 'Golden Delicious' apples to high CO_2 (20%) prior to normal CA storage (2.5% O_2 and 1%CO_2) delayed firmness and titratable acidity loss during storage. Bramlage et al. (4) found that firmness loss was retarded in 'McIntosh' apples after exposure to 12% CO_2 and 3 to 5% O_2 for two weeks followed by standard CA storage alone. Firmness loss was dependent on level of maturity at harvest, and was retarded to a greater extent when prestorage treatment time and CO_2 concentration were increased. Unfortunately, this beneficial effect of high CO_2 resulted in external and internal injury. Olsen and Bartram (16) reported that high CO_2 treatment of 'Golden Delicious' apples enhanced firmness retention and permitted the extension of the packing and marketing season. In contrast, Lau and Olsen (13) found that high levels of CO_2 prior to CA storage had no effect on 'Golden Delicious' firmness. Lange (12) determined that exposure of apples to CO_2 concentrations above 10% before storage resulted in peel injury and did not aid in firmness

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retention. This study was initiated to determine the response of several strains of 'Gala' apples to high CO_2 treatment prior to CA storage.

Materials and Methods

The study was conducted over three crop seasons (1994, 1995 and 1996) using 3 strains of 'Gala' apples ('Crimson Gala', 'Imperial Gala' and 'Royal Gala'). During the first year of the study, only the 'Royal Gala' strain was used. In the subsequent two years all 3 strains were evaluated. Each year, 'Gala' apples were harvested from orchards in three locations in Washington state on two dates, commencing at commercial harvest and again 7 days later. On each harvest date, 130 fruit (150 fruit in 1994) were harvested from each of 3 trees of each strain. Fruit with the most red color were collected at each harvest. Immediately after harvest, 10 fruit from each harvest sample were evaluated for maturity. The remaining 120 fruit in each harvest sample were divided into three separate subgroups. One subgroup of 40 fruit was placed directly into CA storage at 1% O_2 and 1% CO_2. A second subgroup of 40 fruit was exposed to 12% CO_2 for 7 days prior to storage under the same CA conditions. A third subgroup of 40 fruit was exposed to 12% CO_2 for 14 days prior to storage under the same CA conditions. Atmospheres in the CA chambers (0.14 m^3) were established in less than 12 hours. Atmospheres were maintained at $\pm 0.1\%$ using a computer control system (Technical Consulting Service, Chelan, WA). Nitrogen was supplied by a membrane gas separation system (Shifletts, Inc., Wenatchee, WA). CA fruit were held at 1°C for 90 days and 150 days. After each storage period, 20 fruit were removed for quality assessment. Ten fruit were evaluated immediately after removal from storage and the remaining 10 fruit evaluated after an additional 7 days of storage at ambient temperature (20°C). Fruit quality was evaluated by measuring flesh firmness, external and internal color, soluble solids content (SSC), titratable acidity (TA), starch and carbohydrate content. Each fruit was also examined visually for defects.

Firmness was determined using the TA-XT2 Texture Analysis (Texture Technologies Corp., Scarsdale, NY) equipped with a 11.1-mm diameter probe. External and internal color were determined with a Minolta Chromameter, model CR 300 (Osaka, Japan) using the Hunter L*, a*, b* system for calculation of hue values (10). 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. Fruit skin color was also determined in 1995 and 1996 using the Agtron color meter, model E5-W (Magnuson Eng., Reno, NV). The average value of 10 fruit was reported for all color analyses. Starch was determined on a scale of 1 to 5 as described by the Washington Apple Maturity Handbook (1).

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. SSC of the extracted juice was determined with an Abbe-type refractometer calibrated at 20°C. Sucrose, glucose and fructose contents were determined by the high performance chromatography method described by Bio-Rad (Bio-Rad, Richmond, CA).

The fruit from each strain originated in a different commercial orchard in each location in Washington state. Therefore, each strain represented a separate trial. For each strain, three trees selected for their uniformity were used to collect sample fruit. The same three trees in each orchard were used throughout the three years ('Royal') and two years ('Crimson,' 'Imperial') of the trial. Each trial of each strain consisted of the evaluation of four factors [harvest date (2 levels), pre-storage exposure to high CO_2 (3 levels), storage time (2 levels), and post-storage ambient temperature exposure time (2 levels)] in a factorial treatment arrangement in a completely randomized design.

Prior to statistical analysis, the data from the three trees in each plot in each location were averaged to produce a single plot mean value for each data variable. Plot means were then evaluated by analysis of variance using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) program package (SAS, Inc., Cary, NC), using data from each year as replicates. Based on significant F tests, means were separated by Tukey's Honestly Significant Difference (HSD) test (6).

Results and Discussion

During the first year of this study (1994) there was a good indication that prestorage exposure to high CO_2 had a direct influence on the quality of 'Royal Gala' apples and the longer the time of exposure to CO_2 the superior the quality retention. Firmness, color, SSC and carbohydrate retention were the quality factors enhanced by the exposure of 'Royal Gala' apples to high CO_2 in 1994 (data not shown).

In the following seasons, high CO_2 treatment did not affect firmness retention, for 'Royal Gala,' 'Imperial Gala' and 'Crimson Gala' apples (Table 1). There was no difference in the poststorage firmness of any strain of 'Gala' apple prior to or after ripening, regardless of CO_2 treatment. Time of harvest and ripening did have a direct influence on the firmness of both 'Royal Gala' and 'Crimson Gala'. A 7-day delay in harvest and 7 days of ripening had no influence on the firmness of 'Imperial Gala'.

The SSC and TA of 'Royal Gala,' 'Imperial Gala' and 'Crimson Gala' were not influenced by prestorage CO_2 treatment (Table 1). SSC of 'Royal Gala' and 'Crimson Gala' apples was enhanced with a 7-day delay in harvest. The SSC of 'Imperial Gala' was not influenced by a delay in harvest. Titratable acidity was reduced by harvest delay in both 'Royal Gala' and 'Imperial Gala,' but not in 'Crimson Gala' apples. A ripening time of 7 days did not change the titratable acidity of 'Royal Gala' or 'Imperial Gala' , but did reduce

Table 1. Firmness, total soluble solids and titratable acidity of 'Royal Gala,' 'Imperial Gala' and 'Crimson Gala' after 150 days of storage as influenced by storage treatment, harvest date and ripening.

	'Royal Gala'			'Imperial Gala'			'Crimson Gala'		
Treatment	Firmness (N)	SSC (%)	Titratable acidity (% malic)	Firmness (N)	SSC (%)	Titratable acidity (% malic)	Firmness (N)	SSC (%)	Titratable acidity (% malic)
Storage									
CA 1[z]	65.9a[w]	12.7a	0.39a	77.7a	14.3a	0.35a	74.9a	14.4a	0.42a
CA 2[y]	66.0a	12.9a	0.38a	77.9a	14.2a	0.34a	75.8a	14.4a	0.41a
CA 3[x]	64.8a	12.8a	0.37a	78.3a	14.3a	0.33a	77.6a	14.4a	0.40a
Harvest Date									
1	70.1a	12.6b	0.41a	78.6a	14.4a	0.36a	76.5a	14.3b	0.41a
2	61.1b	13.0a	0.37b	77.3a	14.2a	0.32b	74.7b	14.5a	0.41a
Ripening Days									
0	67.2a	12.9a	0.39a	79.0a	14.3a	0.35a	78.3a	14.3b	0.43a
7	64.0b	12.8a	0.38a	77.0a	14.2a	0.33a	77.2b	14.5a	0.39b
Interaction									
H x S	ns	ns	ns	ns	ns	ns	ns	*	ns
H x R	ns	ns	ns	ns	ns	ns	ns	ns	ns
S x R	ns	ns	ns	ns	ns	ns	ns	ns	ns
H x S x R	ns	ns	ns	ns	ns	ns	ns	ns	ns

[z]Normal CA (1% O_2 & 1% CO_2).
[y]Normal CA established after 7 days 12% CO_2 treatment.
[x]Normal CA established after 14 days 12% CO_2 treatment.
[w]Means in a column within treatments not followed by a common letter are significantly different by Tukey's HSD test, or by analysis of variance ($P \leq 0.05$).

Table 2. Exterior color of 'Royal Gala,' 'Imperial Gala' and 'Crimson Gala' after 150 days of storage as influenced by storage treatment, harvest date and ripening.

	'Royal Gala'			'Imperial Gala'			'Crimson Gala'		
Treatment	L*	hue	E5-W	L*	hue	E5-W	L*	hue	E5-W
Storage									
CA 1[z]	59.5a	42.1a	81.4a	56.6a	37.9a	85.7a	48.4a	32.7a	90.1a
CA 2[y]	59.3a	41.6a	81.5a	59.1a	42.4a	84.3a	49.4a	31.9a	89.5a
CA 3[x]	60.2a	42.4a	81.6a	57.4a	39.0a	85.3a	49.5a	31.6a	90.1a
Harvest Date									
1	59.3a	43.7a	80.7b	57.1a	40.3a	85.3a	46.8b	33.7a	90.8a
2	60.0a	40.4b	82.3a	58.3a	39.3b	85.0a	51.4a	30.5b	89.0b
Ripening Days									
0	59.8a	39.7b	82.0a	58.4a	38.1b	85.2a	48.3a	32.3a	90.1a
7	59.6a	44.4a	81.0a	57.0a	41.4a	85.0a	49.8a	31.8a	89.7a
Interaction									
H x S	ns	ns	ns	ns	ns	ns	ns	ns	ns
H x R	ns	ns	ns	ns	ns	ns	ns	ns	ns
S x R	ns	ns	ns	ns	ns	ns	ns	ns	ns
H x S x R	ns	ns	ns	ns	ns	ns	ns	ns	ns

[z]Normal CA (1% O_2 & 1% CO_2).
[y]Normal CA established after 7 days 12% CO_2 treatment.
[x]Normal CA established after 14 days 12% CO_2 treatment.
[w]Means in a column within treatments not followed by a common letter are significantly different by Tukey's HSD test, or by analysis of variance ($P \leq 0.05$).

the titratable acidity of 'Crimson Gala'. This change in SSC and titratable acidity due to harvest and ripening would have an influence on the SSC/TA ratio, which can have a major influence on the consumer acceptance of apples and an increase in the ratio due to harvest or ripening may have an impact on acceptability. Consumers typically prefer apples with higher SSC, TA and SSC/TA ratio; the differences in TA and SSC/TA ratio reported here suggest that consumers would preferentially choose CA-stored 'Gala' apples.

Prestorage high CO_2 exposure did not change or enhance the exterior color retention of either 'Royal Gala,' 'Imperial Gala,' or 'Crimson Gala' using either the Hunter or Agtron color system. A 7-day delay in harvest enhanced red color of all the strains in the study as evidenced by reduced hue values for 'Royal Gala,' 'Imperial Gala' and 'Crimson Gala' (Table 2). This exterior color enhancement due to harvest delay was evident using Agtron E5-W values for only 'Royal Gala' apples. Agtron E5-W values for red color did not change due to harvest delay for 'Imperial Gala' and were reduced when 'Crimson Gala' was considered. Hunter L* values for color were also increased in 'Crimson Gala' apples as a result of harvest delay, which would agree with reduced Agtron values. A ripening time of 7 days reduced the red color for 'Royal Gala' and 'Imperial Gala' apples as evidenced by the increased hue values.

Prestorage high CO_2 treatment had no influence on the internal color of 'Royal Gala,' 'Imperial Gala' or 'Crimson Gala' apples (Table 3). Hue value was reduced in 'Crimson Gala' apples as a result of prestorage exposure to high CO_2 for 7 days, but this trend did not continue when 'Crimson Gala' apples were exposed to high CO_2 for 14 days. A delay in harvest of 7 days resulted in a change in the interior color of only 'Crimson Gala' apples. Ripening time also produced a decrease in interior hue values, but the change was evident in 'Royal Gala,' 'Imperial Gala' and 'Crimson Gala' apples. These changes in interior color as a result of harvest delay or ripening would be visible to the consumer given the difference in hue

Table 3. Interior color of 'Royal Gala,' 'Imperial Gala' and 'Crimson Gala' after 150 days of storage as influenced by storage treatment, harvest date and ripening.

Treatment	Royal Gala'		'Imperial Gala'		'Crimson Gala'	
	L*	hue	L*	hue	L*	hue
Storage						
CA 1[z]	78.1a	93.8a	76.4a	93.0a	78.7a	94.6a
CA 2[y]	77.4a	93.9a	76.3a	92.7a	77.9a	93.5b
CA 3[x]	77.4a	93.8a	76.9a	92.7a	77.8a	94.7a
Harvest Date						
1	77.9a	94.1a	77.3a	93.1a	78.5a	95.2a
2	77.4a	93.6a	78.5a	92.4a	77.8a	93.3b
Ripening Days						
0	77.2a	94.8a	75.7a	93.7a	77.6a	95.1a
7	78.0a	92.9b	77.4a	91.9b	78.7a	93.4b
Interaction						
H x S	ns	ns	ns	ns	ns	ns
H x R	ns	ns	ns	ns	ns	ns
S x R	ns	ns	ns	ns	ns	ns
H x S x R	ns	ns	ns	ns	ns	ns

[z]Normal CA (1% O_2 & 1% CO_2).
[y]Normal CA established after 7 days 12% CO_2 treatment.
[x]Normal CA established after 14 days 12% CO_2 treatment.
[w]Means in a column within treatments not followed by a common letter are significantly different by Tukey's HSD test or analysis of variance ($P \leq 0.05$).

Table 4. Carbohydrate content of 'Royal Gala,' 'Imperial Gala' and 'Crimson Gala' apples as influenced by storage treatment and time of harvest.

Strain	Treatment	Carbohydrates (mg/ml)			
		Sucrose	Glucose	Fructose	Total
'Royal'					
	CA 1[z]	3.12a[w]	1.62a	7.38a	12.30a
	CA 2[y]	2.99a	1.48a	6.84a	11.55b
	CA 3[x]	2.82a	1.62a	6.87a	11.55b
	Harvest 1	2.93a	1.62a	6.93b	11.78a
	2	3.03a	1.52a	7.12a	11.81a
'Imperial'					
	CA 1	3.49a	1.98a	7.96a	13.82a
	CA 2	3.34a	1.50a	7.72a	13.20a
	CA 3	3.07b	1.99a	7.91a	13.18a
	Harvest 1	2.80b	1.87b	7.46b	12.56b
	2	3.80a	2.04a	8.27a	14.23a
'Crimson'					
	CA 1	3.84a	1.76a	6.61a	12.58a
	CA 2	3.64a	1.75a	6.40a	12.28a
	CA 3	3.67a	1.66a	6.39a	12.25a
	Harvest 1	3.50b	1.61b	6.11b	11.60b
	2	3.94a	1.84a	6.83a	13.14a

[z]Normal CA (1% O_2 & 1% CO_2) established immediately.
[y]Normal CA established after 7 days 12% CO_2.
[x]Normal CA established after 14 days 12% CO_2.
[w]Means in a column within treatments not followed by a common letter are significantly different by Tukey's HSD test or analysis of variance ($P \leq 0.05$).

values (2 units) and could possible impact consumer acceptance (10)

CO_2 treatment influenced the carbohydrate content of both 'Royal Gala' and 'Imperial Gala' apples, particularly total carbohydrates and sucrose (Table 4). Total carbohydrates were reduced in 'Royal Gala' apples with CO_2 treatment for either 7-or 14-day exposure time. Differences in sucrose between storage treatments was also present, but significant reduction was evident for only 'Imperial Gala' apples treated with high CO_2 for 14 days. No difference was evident between storage treatment for either glucose, fructose or sorbitol regardless of the strain of 'Gala' apples considered. A 7-day delay in harvest increased fructose content in 'Royal Gala' apples, and the sucrose, glucose fructose and total carbohydrate content in both ' Imperial Gala' and 'Crimson Gala' apples Increased sweetness with good acid content is much preferred by the consumer; the differences in carbohydrates resulting from prestorage high CO_2 treatment and delay in harvest could affect consumer acceptance (17). Although there were differences among strains in carbohydrate content, those differences could not be statistically tested due to the non-random distribution of strains in test orchards.

Harvest date had a major influence on the quality characteristics of all 'Gala' strains in this study, regardless of CO_2 treatment. A difference of one week in the harvest of 'Gala' apples resulted in reduced flesh firmness and reduced TA, but increased color and carbohydrate content. There was very little relationship between effects of high CO_2 treatment and maturity or harvest date. Use of high CO_2 (12%) prior to normal CA was not found to be advantageous for the storage of 'Crimson,' 'Royal,' or 'Imperial Gala' apples.

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