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Quality of 'Fuji' Apples After Regular and Controlled Atmosphere Storage

S. R. DRAKE[1] AND D. C. ELFVING[2]

Abstract

The postharvest quality of three strains (Naga-fu 2, 6 and 12) of 'Fuji' apples from two growing locations was evaluated over four storage seasons. Fruit quality was determined at harvest, after 90 days of regular atmosphere (RA) storage and after 210 days of controlled atmosphere (CA) storage at 1% O_2 & 1% CO_2, 1% O_2 & 3% CO_2 and 1% O_2 & 5% CO_2. Strains of 'Fuji' apples had very little influence on quality at harvest or after RA storage. After CA storage some quality differences were evident between strains, particularly, for red color development, which was greater in Naga-fu 2. Growing location had an influence on quality parameters of 'Fuji' apples at harvest and after storage. These quality differences determined for 'Fuji' apples between growing locations may offer an explanation of the differences reported for 'Fuji' apple quality of the same strain. Carbon dioxide level in the storage atmosphere had a direct influence on fruit quality. Fruit stored at 5% CO_2 displayed more internal breakdown at cavity development and less scald development than fruit stored at 1% and 3% CO_2. 'Fuji' apples stored well and maintained good quality at 3% CO_2, which would be less costly to maintain than 1% CO_2, the standard recommendation for the CA storage of 'Fuji' apples.

Additional index words. strains (Nagafu 2, 6 and 12), high carbon dioxide, *Malus* x *domestica*.

'Fuji' apple, introduced in 1962 (20), has become a commercially important cultivar in WA in recent years. The growth in popularity of 'Fuji' apples in the US has been impressive; total production reached 160,607 bushels in 1997 (4). 'Fuji' apples store well and typically do not exhibit quality loss after storage to the extent of other commercially grown cultivars (21). Suitable color development at harvest can be a serious problem associated with this cultivar. Numerous strains have been selected for improved color; many of these strains are unstable for the improved color characteristic (11).

Long term storage is a requirement for orderly marketing; however, the long-term commercial storage of 'Fuji' apples has produced varying degrees of success. Meheriuk (12) reported that the best controlled-atmosphere (CA) environment for the storage of 'Fuji' apples was 1.0-2.5% O_2 and 0.7-2.0% CO_2. He also found that lower O_2 may cause off-flavors and higher CO_2 may cause internal injury and increased scald in 'Fuji' apples stored for longer than 7 months. Earlier research determined that 'Fuji' apples stored well in 2.8% CO_2 if the apples were slightly immature at harvest (14). Other reports indicated that the incidence of internal browning in 'Fuji' apples was greatly reduced when stored in 1% or less CO_2 (7, 8, 12). Brackmann et al. (3) found that the best atmosphere for quality retention of 'Fuji' apples was 1% O_2 and 0% CO_2, but the development of disorders was not influenced by this low CO_2 atmosphere. Dilley et al. (5) reported that the best general atmosphere for the long term storage of apples was 1.5% O_2 and 3% CO_2. Working with 'Empire' apples, Wang et al. (17) found that some disorders associated with exposure to CO_2 during storage could be eliminated with a postharvest acclimatization period prior to storage in high CO_2.

Removal of CO_2 during long term storage of apples is a costly and time consuming operation. Not only is the cost of CO_2 removal itself a concern, but also one

[1]Research Horticulturist, USDA, ARS-TFRL, 1104 N. Western Ave., Wenatchee, WA. 98801.
[2]Horticulturist, Washington State Univ., Tree Fruit Research and Extension Center, 1100 N. Western Ave., Wenatchee, WA 98801.

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must consider the additional cost of purchase and installation of this type of equipment (2, 6, 18). Drake et al. (6) found no quality problems associated with the long term storage of 'Delicious' apples in 3% CO_2. Van der Merwe et al. (16) reported that both 'Topred Delicious' and 'Granny Smith' apples maintained good quality when stored for long periods of time in 3% CO_2. Watkins et al. (19) found little difference in the quality of 'Granny Smith' apples when comparing atmospheres containing different levels of CO_2. High CO_2 reduced the incidence of disease in apples stored long-term (15). Hong et al. (9) determined that 4 cultivars of apples, including 'Fuji', maintained good quality when stored in 1% O_2 and 3% CO_2. There are conflicting results concerning the appropriate CO_2 content of the atmosphere for the successful long-term CA storage of apples. This study was initiated to determine if the differing responses reported for 'Fuji' apples could be associated with strain or growing location and to identify the best CA atmosphere for the long term economic storage of 'Fuji' apples.

Materials and Methods

For this study, 'Fuji' apples (strains Nagafu 2, 6 and 12) were harvested from two commercial orchards, one located in Orondo, WA and the other in Milton-Freewater, OR. The same trial was repeated in four successive years (1993-1996). All three strains were present as separate 3-row units side by side in each of the orchards used for sample collections. All trees used for sample collections were located in middle rows in each sampled orchard in both locations. The trees were on M.26 EMLA rootstock and received standard commercial horticultural practices over the four years of this study. One to two days prior to commercial harvest each year, 270 apples of uniform size and color were harvested at random from a single 6-tree plot in each of three rows of each individual strain for a total of 810 apples from each location. Fruit from each row of each strain were kept separate during storage and post-storage evaluations. Differences between the orchard locations dictated that the harvest dates in the two orchards were approximately 10 days apart each year. Immediately after harvest the apples were transported to the USDA, ARS, TFRL in Wenatchee, WA. Upon arrival at the laboratory, the apples from each location, strain and row were divided at random into 5 groups. One group of 10 apples was used immediately to assess harvest maturity parameters. A second group of 20 apples was placed in regular atmosphere (RA) storage at 1°C and held for 90 days. The three remaining groups of 20 apples were placed into different CA atmospheres. The atmospheres used in this study were 1% O_2 + 1% CO_2, 1% O_2 + 3% CO_2 and 1% O_2 + 5% CO_2. All CA atmospheres were established within 24 hours of harvest and were maintained throughout the storage period at ±0.1% using a computer control system (Technical Consulting Services, Chelan, WA). Nitrogen for this purge type CA system was supplied by a membrane separation system and bottled CO_2 was used to maintain appropriate CO_2 levels as necessary. All gases were humidified prior to injection. All fruit in CA atmospheres were held at 1°C for 180 days.

Post-storage quality was assessed on 20 apples from each strain, storage condition and row (sample). Ten apples were evaluated immediately after removal from storage and the remaining 10 were allowed to ripen for 7 days at ambient temperature (≈20°C) before evaluation. Quality factors evaluated were firmness, soluble solids content (SSC), titratable acidity (TA), external and internal color, carbohydrates, and visible disorders (external and internal). Firmness was determined at two locations per fruit with the TA-XT2 Texture Analyzer (Texture Technologies, Scarsdale, NY) equipped with a 11.1 mm probe. Single cross-sectional slices from each of the same 10 fruit were composited, ground, and 30 ml. of juice were taken for determination of SSC, TA and carbohydrates. An Abbé type refractometer with a sucrose scale calibrated at 20°C was used to determine SSC. TA was measured with

a Radiometer titrator, model TTT 85 (Radiometer, Copenhagen, Sweden). Acids were titrated to pH 8.2 with 0.1N NaOH and expressed as percent malic acid. External and internal color were determined with The Color Machine (Pacific Scientific, Silver Springs, MD) using the Hunter L*, a*, b* system and calculated hue (h°) values (Hunter and Harold, 1987). External color was measured on the equatorial plane on the two sides of each fruit 90° from the most exposed side. Carbohydrates (sucrose, glucose, fructose and sorbitol) and total carbohydrates were determined by HPLC procedures described by Bio-Rad (Bio-Rad, Richmond, CA). Disorders (CO_2 injury, internal breakdown, and scald) were visually assessed by two laboratory personnel and expressed as the percentage of each fruit sample showing the disorder.

The same six trees in each row in each orchard were harvested throughout the four years of the trial. The experiment consisted of the evaluation of four factors [location (2 levels), strain (3 levels), storage regime (4 levels), and post-storage ambient temperature exposure time (2 levels)] in a factorial treatment arrangement in a completely randomized design using years as replications. Prior to statistical analysis, data from the three rows of each strain in each location were averaged to produce a single strain plot mean value for each data variable for each year. 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

At harvest, 'Fuji' apples displayed excellent firmness, high SSC and TA, and good total carbohydrates, but poor color. There were no differences in firmness, SSC, total carbohydrates, TA , starch or color among the 'Fuji' strains. None of the strains developed sufficient red color for good marketing. This lack of red color development was evident when either hue or E5-W color analysis was considered.

'Fuji' apples grown in Milton-Freewater had higher SSC, total carbohydrates and TA content than apples grown in Orondo. However, no differences in firmness, starch content, or color were evident between the two growing locations. The higher SSC, total carbohydrates and TA in apples grown at Milton-Freewater could result in better consumer acceptance. However, this difference in eating quality could not be identified from exterior appearance, particularly color.

After 90 days of RA storage there was no difference in the quality attributes of 'Fuji' apples regardless of strain or growing location. Firmness, SSC, TA and exterior color attributes were commercially acceptable. No change in color occurred during 90 days of RA storage.

After 210 days of CA storage no change in firmness, SSC or TA was evident among the three 'Fuji' apple strains (Table 1). Firmness, SSC and TA values after CA storage were similar to the values determined at harvest. However, there were differences in color between the three 'Fuji' apple strains. Apples of the Nagafu 6 strain had less red color than either Nagafu 2 or 12, particularly when hue was considered (lower hue values indicate redder fruit). There were also some Hunter L* color differences among the three strains, with apples of the Nagafu 6 strain displaying higher L* values or lighter color than apples of the Nagafu 2 strain. Apples of the Nagafu 12 strain displayed Hunter L* values intermediate between Nagafu 2 and 6. If only E5-W (higher number = redder fruit) color values were considered, no difference in red color was evident among 'Fuji' strains in this study. This color information does not agree completely with other reports (1, 10), which have indicated that Nagafu 2 has more red color than either Nagafu 6 or 12.

Growing location had a strong influence on the quality attributes of 'Fuji' apples after 210 days of CA storage (Table 1).

Table 1. Quality attributes of 'Fuji' apples (Nagafu 2, 6 and 12) grown in Milton-Freewater, OR and Orondo, WA after 210 days of controlled atmosphere.

Treatment	Firmness (N)	SSC (%)	Titratable acidity (% malic)	Exterior Color		
				Hunter L	hue	E5-W
Strain						
2	72.1a	15.9a	0.32a	53.4b	53.7b	74.7a
6	72.1a	15.9a	0.31a	55.7a	59.6a	72.6a
12	72.3a	16.1a	0.31a	54.1b	53.9b	74.7a
Location						
MF	71.3b	16.3a	0.33a	52.9b	53.0b	75.6a
OR	73.1a	15.6b	0.30b	55.9a	58.5a	72.5b
Storage						
1% O_2 & 1% CO_2	72.1a	15.9a	0.31a	53.8a	56.0a	74.0a
1% O_2 & 3% CO_2	72.5a	16.0a	0.32a	54.1a	54.8a	74.4a
1% O_2 & 5% CO_2	72.0a	16.0a	0.31a	55.3a	56.4a	73.7a
Interactions						
Str x Loc	ns	**	ns	ns	ns	ns
Str x Sto	ns	ns	ns	ns	ns	ns
Loc x Sto	ns	ns	ns	ns	ns	ns
Str x Loc x Sto	ns	ns	ns	ns	ns	ns

[z]Means in a column, within treatments, not followed by a common letter are significantly different ($P \leq 0.05$).

'Fuji' apples from Milton-Freewater had higher SSC and TA values and more red color (hue and E5-W values) than 'Fuji' apples from Orondo. Firmness values for 'Fuji' apples from the two growing areas differed by almost 2N and were significant. This degree of difference in firmness is considered of commercial significance. In addition, differences in red color between the two growing locations were great enough (1 unit or more) to be detectable by the average consumer (10).

The amount of CO_2 in the CA storage environment had no influence on the quality attributes of 'Fuji' apples (Table 1). Several studies (3, 7, 8, 9) have reported differences in the quality of 'Fuji' apples depending upon the amount of CO_2 in the storage atmosphere. In this study, no differences in firmness, SSC, TA or color were noted for 'Fuji' apples stored under controlled atmospheres containing between 1% and 5% CO_2.

The incidence of physiological disorders after 210 days of CA storage was not related to strain (Table 2). Scald, internal breakdown and cavities were observed in each strain, but the percentage of fruit affected by each disorder was both small and similar among strains. Growing location had a major influence on the incidence of all the disorders evaluated in this study. 'Fuji' apples grown in Orondo, WA dis-

Table 2. Disorders of 'Fuji' apples (Nagafu 2, 6 and 12) grown in Milton-Freewater, OR and Orondo, WA after 210 days of controlled atmosphere.

Treatment	(%) Scald	(%) Internal Breakdown	(%) Cavities
Strain			
2	0.3a[z]	3.0a	1.1a
6	0.4a	1.9a	0.7a
12	0.2a	1.6a	0.9a
Location			
MF	0.0b	0.4a	0.2b
OR	1.1a	5.1a	2.0a
Storage			
1% O_2 + 1% CO_2	0.4a	1.7b	0.4b
1% O_2 + 3% CO_2	0.4a	0.9b	0.3b
1% O_2 + 5% CO_2	0.1b	4.6a	2.7a
Ripening			
0	0.1b	2.1a	0.7a
7	0.5a	2.2a	1.1a

[z]Means in a column, within treatments, not followed by a common letter are significantly different ($P \leq 0.05$).

played significantly greater amounts of scald, internal breakdown and cavities compared to 'Fuji' apples grown in Milton-Freewater, OR. The incidence of scald in all strains tested was significantly reduced by the concentration of CO_2 in the storage atmosphere. Little scald development was evident in 'Fuji' apples at 5% CO_2 compared to scald incidence at 1% and 3% CO_2. In contrast, at 5% CO_2 both internal breakdown and cavity development were significantly greater compared to 'Fuji' apples stored in 1% and 3% CO_2. After 7 days of exposure to room temperature (simulated ripening), scald was increased with no change in internal breakdown or cavity formation. This increase in internal breakdown and cavity development at high CO_2 levels in the storage atmosphere has been noted in previous research (3, 8, 12), but disorders increased when the storage atmosphere was above 1% CO_2. Hong et al. (9) reported no increase in physiological problems immediately after storage with 'Fuji' apples stored in 3% CO_2. During a 7-day ripening period in their study, scald was the only physiological disorder that increased. Similarly, in this study, scald was the only disorder affected by 7 days of ripening.

Conclusions

The strains used in this study (Nagafu 2, 6 & 12) have very little influence on the quality of 'Fuji' apples at harvest or after RA storage. After CA storage some quality differences are evident between strains, particularly for the red color development found in Nagafu 2, which may influence consumer acceptance. Growing location had an influence on the quality of 'Fuji' apples at harvest and after CA storage. Although both sites are located in the cold desert environment of eastern Washington and Oregon, they differ in many climatic characteristics, including length of growing season. The specific factors at each site that influenced the fruit quality observed in this study are unknown. However, this quality difference in 'Fuji' apples due to growing location may offer an explanation for differences reported for 'Fuji' apples of the same strain. Carbon dioxide in the storage atmosphere does have a major influence on the quality of 'Fuji' apples, but 'Fuji' apples store well and maintain good quality in a CO_2 atmosphere of 3%, which is much less costly to maintain than 1% CO_2. The strains of 'Fuji' apples in this study all stored very well and maintained good quality during RA or CA storage. The only quality difference that was evident between the three strains was color, and that only after long-term CA storage.

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