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# Maturity and Storage Quality of 'Jonagold' Apples Related to Starch Index

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## Abstract

Quality of 'Jonagold' apples that were harvested at two maturities as determined by starch index was evaluated over three seasons. Apple quality was evaluated after harvest and after regular atmosphere (RA) and controlled atmosphere (CA) storage at 2% $O_2$ and 3% $CO_2$, or 1% $O_2$ and 1% $CO_2$. At harvest, differences in firmness, soluble solids content, acids and both exterior and interior color was evident between apples harvested at starch index 2 and 4. Apples harvested at a starch index of 2 maintained good quality during 50 days of RA storage and 120 days of CA storage. Delay in the time to establish CA influenced both firmness and acid content of 'Jonagold' apples. The best CA storage atmosphere to maintain the quality of 'Jonagold' apples was 1% $O_2$ & 1% $CO_2$.

Jonagold' has become a commercially important apple cultivar in recent years. Growth in popularity of 'Jonagold' has been steady; total production has reached 962,000 boxes in Washington state alone (19). 'Jonagold' apples are not suitable for long-term storage because of quality losses during and after storage. If production of this cultivar is to continue and increase enhanced storage procedures must be determined because long-term storage is usually a requirement for marketing. To date, the long-term commercial storage of 'Jonagold' apples has produced varying degrees of success.

One of the major consideration for grade determination of apples is color (17). In certain growing seasons, fruit will reach maturity prior to obtaining good color. Once harvested, it may take two weeks before fruit can be stored and controlled conditions (CA) properly established. Researchers (2, 8, 10, 11, 12) have found that the more rapid the desired CA is established the better the quality of the fruit after storage. Delays between harvest and establishment of proper atmosphere result in fruit quality loss during storage. Proper harvest maturity for CA storage of apples has been a major concern since the initiation of CA storage.

Meheriuk (13) reported the CA environment for the storage of 'Jonagold' apples was 2% $O_2$ with a range of $CO_2$ from 1 to 4.5%. Lau (9) determined that 'Jonagold' apples, picked at the proper maturity stored well in regular atmosphere (RA) until February and in CA (1.5% $O_2$ and 1.5% $CO_2$) until June. Drake (4) reported that 'Jonagold' apples maintained quality for only short periods of time regardless of type of storage.

Maturity at harvest has a major influence on the storage quality of apples. At present, color firmness, soluble solids, ethylene content and starch are used as indices of maturity (18). Starch has long been used as a maturity indicator for apples. Using starch as a maturity indicator has proven successful in many studies (3, 9, 15, 16). Conversely, other researchers (1, 7) have indicated that starch is not a reliable indicator of apple maturity. Regardless, starch clearing is one of the major indicators of maturity in the apple industry today (18). In the Washington state apple industry, there is some concern about the usefulness of a starch index as a predictor of maturity for controlled atmosphere (CA) storage of 'Jonagold' apples, and the proper atmosphere for storage of this cultivar. This study was initiated to determine

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the suitability of using a starch index to determine optimum maturity for the storage of 'Jonagold' apples and evaluate quality during RA and CA storage.

## Materials and Methods

'Jonagold' apples were harvested from three locations in Washington state. The trees, grown on M.26 rootstock, were approximately 10 years-old when this study was initiated. Ten apples were harvested twice weekly from the same 4 trees in each location starting in mid-August. Care was taken to insure that the apples used were from similar locations, 1-2 m. above the ground, around the circumference of the tree at each sampling period. Starch content was determined by standard procedures using a starch index of 1 to 6 (18). When the average starch index at each location was 2.0, 110 fruit from each of 4 rows of trees were harvested. Quality (firmness, SSC, TA, color and wieght) was determined immediately on ten fruit from each tree. One to two weeks later when the average starch index for each location was 4.0, 110 fruit were harvested and handled similar to the previous harvest. In 1997 and 1998, within 12 hours of harvest fruit was placed in CA (2% $O_2$ and 3% $CO_2$) storage and evaluated after 90 and 120 days of storage. In 1998 and 1999, apples were placed in RA and CA storage and evaluated after 50 and 100 days of storage. CA (1% $O_2$ and 1% $CO_2$ or 2% $O_2$ and 3% $CO_2$) was established in <12 hours, or after 10 days in RA. Temperature, in both RA and CA storage was 1°C. After storage, twenty fruit from each row were removed and quality determined that same day on ten fruit. The remaining ten fruit were held at ambient temperature for 7 days when quality was again determined. Quality factors evaluated were starch (by color), weight (harvest only) firmness, peel and flesh color, soluble solids content (SSC), titratable acidity (TA) and physiological disorders (at harvest and after storage).

Firmness was determined at two locations per fruit with the TA-XT2 Texture Analyzer, equipped with a 11.1 mm probe. Peel and flesh color was determined with The Color Machine using the Hunter L*, a*, b* system and calculated hue values (6). Soluble solids content (SSC) and titratable acidity (TA) were determined from an aliquot of expressed juice taken from a cross-sectional slice from each of the same 10 fruit. An Abbe 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. Acids were titrated to pH 8.2 with 0.1 N NaOH and expressed as percent malic acid. Analysis of variance was determined using MSTAT-C (1988) with starch as the main plot and atmosphere, storage and ripening as a subplot where applicable. Years were pooled for data analysis. Means were separated using Tukey's test ($P < 0.05$).

## Results and Discussion

'Jonagold' apples were considered properly matured for CA storage at a starch index of 2 to 3 (18). In this study, firmness, SSC and TA were at levels generally considered acceptable for the long-term storage of this apple cultivar at a starch index of 2 (Table 1). Time required for starch index to change from 2 to 4 resulted in no increase in fruit size. However, changes in starch index resulted in a decrease of 11% in firmness and 21% in TA with a considerable increase in color. The peel color change was evident with a distinct change in a* values that would be evident to the human eye as an increase in red color. Significant changes in hue values were also present, indicating a color change to more yellow/red with less green. No change in L* or b* values occurred in 'Jonagold' apples as starch index increased from 2 to 4. Change in flesh color was also evident with increased L*, a* and b* and decreased hue values as starch level increased from 2 to 4. Change in flesh color values would indicate a less green and a more yellow color with a starch index of 4 compared to apples with a starch index of 2. This change in flesh color would be evident to the human eye in that all color values changed by more than 1.0 Hunter units (6).

**Table 1. Quality attributes for 'Jonagold' apples harvested at starch index of 2, or 4, three year average.**

| Starch Index | Weight (g) | Firmness (N) | SSC (%) | TA (% malic) | Hunter Color: Peel Color L* | a* | b* | hue | Flesh Color L* | a* | b* | hue |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 243.6a[z] | 74.5a | 12.7b | 0.69a | 62.8a | –8.3b | 31.4a | 104.8a | 73.7b | –4.0b | 18.9b | 102.0a |
| 4 | 259.4a | 66.4b | 13.5a | 0.54b | 66.3a | 2.3a | 29.1a | 83.9b | 76.5a | –2.5a | 23.4a | 96.1b |

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

Starch index at harvest had an influence on the quality attributes of 'Jonagold' apples after 90 days of RA (Table 2). 'Jonagold' apples harvested at starch index of 4 contained 20% less acidity than apples harvested at a starch index of 2. This drop in TA would have a major impact on the flavor of the apples, particularly when no change in SSC levels were noted with a change in starch from 2 to 4. A change in the ratio of SSC to TA can impact flavor (14). This change in flavor, for 'Jonagold' apples harvested at a starch index of 4, coupled with a 13% loss in firmness, would reduce acceptance of this apple after 90 days of RA storage. Exterior color RA stored apples was similar to color at harvest. Apples harvested at starch index of 4 displayed more red color than apples harvested at a starch index of 2. When grade is considered, color is more of a consideration than flavor (17). At the present there are no firmness standards for 'Jonagold' apples.

Time in RA storage and with subsequent ripening at ambient temperature, reduced firmness and TA; however, red color was enhanced as storage progressed from 50 to 100 days (Table 2). This increase in the red color of the peel was most probably due to a loss of chlorophyll during storage. Ripening for 7 days after storage resulted in increased yellow (higher b* values) and less red color (larger hue values) development. These changes in apple quality attributes, as time in storage and ripening increased, have been documented on other occasions (4, 10, 12).

Starch index influenced the quality attributes of 'Jonagold' apples in CA storage (Table 3). As with apples from RA storage, apples from CA harvested at a starch index of 4 contained less acidity (24%) and were not as firm (11%) as apples harvested at a starch index of 2. The delay of harvest from 7 to 10 days (starch index change from 2 to 4) resulted in increased color for apples from the later harvest with changes in exterior a*, b* and hue values indicating a more yellow less green apple. Interior (L* and hue) color values also indicated a change from green to a more yellow.

**Table 2. Quality attributes for 'Jonagold' apples harvested at starch index of 2, or 4, after 50 and 100 days in regular atmosphere storage and ripening, 1998-99.**

| | Firmness (N) | SSC (%) | TA (% malic) | Hunter Peel Color L* | a* | b* | hue |
|---|---|---|---|---|---|---|---|
| **Starch Index** | | | | | | | |
| 2 | 47.0a[z] | 14.4a | 0.48a | 61.3a | 16.4b | 21.8a | 53.5a |
| 4 | 41.5b | 14.2a | 0.39b | 54.1b | 22.3a | 19.5b | 41.8b |
| **Storage (days)** | | | | | | | |
| 50 | 48.5a | 14.4a | 0.48a | 61.6a | 16.4b | 20.5a | 51.8a |
| 100 | 40.1b | 14.2a | 0.39b | 53.8b | 22.3a | 20.9a | 43.5b |
| **Ripe (days)** | | | | | | | |
| 0 | 48.8a | 14.4a | 0.47a | 57.5a | 19.5a | 19.6b | 46.3b |
| 7 | 39.8b | 14.2a | 0.39b | 57.8a | 19.2a | 21.7a | 49.0a |

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

**Table 3. Quality attributes for 'Jonagold' apples, harvested at a starch index of 2, or 4, after 90 and 120 days in controlled atmosphere (2% $O_2$ & 3% $CO_2$) storage and ripening, 1997-98.**

| | | | | Hunter Color | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Peel Color | | | | Flesh Color | |
| | Firmness (N) | SSC (%) | (% malic) | L* | a* | b* | hue | L* | hue |
| **Starch Index** | | | | | | | | | |
| 2 | 64.8a[z] | 12.9a | 0.52a | 68.9a | −6.2b | 31.9a | 101.2a | 74.3b | 98.5a |
| 4 | 58.6b | 13.1a | 0.42b | 68.7a | 3.1a | 28.1b | 82.7b | 77.1a | 88.2b |
| **Storage (days)** | | | | | | | | | |
| 90 | 61.4a | 13.1a | 0.49a | 68.9a | −1.8a | 30.0a | 92.2a | 76.6a | 96.8a |
| 120 | 61.2a | 12.9a | 0.45b | 68.7a | −1.4a | 30.0a | 91.6a | 74.9b | 89.9a |
| **Ripe (days)** | | | | | | | | | |
| 0 | 63.3a | 13.0a | 0.48a | 68.3b | −2.2b | 29.7a | 93.1a | 76.7a | 97.3a |
| 7 | 59.3b | 13.0a | 0.46b | 69.3a | −1.0a | 30.2a | 90.7b | 74.7b | 89.4b |

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

A thirty day increase in CA storage from 90 to 120 days had no influence on the firmness, SSC and flesh color of 'Jonagold' apples. There was a slight decrease in the flesh L* values as storage increased from 90 to 120 days, but this change would not be of any practical consideration because of the lack of change in flesh hue values. A seven day ripening period resulted in decreased firmness and acids with both peel and flesh color changes. Acid loss during storage was more rapid in apples harvested at starch index 4 compared to the more moderate acid loss in apples harvested at starch iondex 2. After 7 days of ripening, apples were more yellow with a less green flesh color.

Delay in the establishment of CA conditions on 'Jonagold' apples resulted in decreased firmness and a slight change in flesh color (Table 4). SSC, acidity and peel color were not influenced by a 10 day

**Table 4. Quality attributes for 'Jonagold' apples from controlled atmosphere as influenced by time to establish atmosphere, atmosphere level, storage and ripening, harvested at commercial maturity (starch index 2), 1998-99.**

| | | | | Hunter Color | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Peel Color | | | | Flesh Color | |
| | Firmness (N) | SSC (%) | (% malic) | L* | a* | b* | hue | L* | hue |
| **Atmosphere (time to establish)** | | | | | | | | | |
| <12 hours | 57.7a[z] | 14.1a | 0.46a | 48.4a | 20.8a | 15.9a | 38.9a | 75.5b | 95.1a |
| 10 days | 52.1b | 14.2a | 0.47a | 48.5a | 21.0a | 15.7a | 38.2a | 76.0a | 94.2b |
| **Atmosphere** | | | | | | | | | |
| 1% $O_2$ & 1% $CO_2$ | 56.1a | 14.2a | 0.48a | 48.5a | 21.0a | 15.8a | 38.5a | 75.6a | 94.8a |
| 2% $O_2$ & 3% $CO_2$ | 53.7b | 14.1a | 0.46b | 48.4a | 20.8a | 15.7a | 38.6a | 75.9a | 94.5a |
| **Storage (days)** | | | | | | | | | |
| 50 | 56.4a | 13.9b | 0.47a | 48.1a | 21.4a | 16.5a | 39.1a | 75.2a | 94.8a |
| 100 | 53.4b | 14.4a | 0.46b | 48.8a | 20.4b | 15.0b | 38.0a | 76.3a | 94.4a |
| **Ripe (days)** | | | | | | | | | |
| 0 | 59.0a | 14.3a | 0.49a | 48.6a | 19.9b | 15.1b | 38.7a | 77.0a | 95.3a |
| 7 | 50.8b | 14.0b | 0.44b | 48.3a | 21.9a | 16.4a | 38.5a | 74.5b | 94.0b |

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

**Table 5. The relationship between starch level and ripening on the firmness of 'Jonagold' apples from regular and controlled atmosphere storage.**

| | | Storage Type | |
|---|---|---|---|
| Starch Index | Ripening (days) | RA | CA |
| 2 | 0 | 52.1a[z] | 65.6a |
| | 7 | 41.8c | 62.6b |
| 4 | 0 | 45.4b | 61.1b |
| | 7 | 37.9d | 56.1c |
| Storage (days) | Ripening (days) | | |
| 50 | 0 | 56.0a | 63.7a |
| | 7 | 41.0c | 64.4a |
| 100 | 0 | 41.5b | 59.1b |
| | 7 | 38.7d | 58.1b |

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

delay in the establishment of CA. Change in flesh color to a lighter (higher L*) less green (lower hue) with delayed CA establishment would not be considered of any consequence, since the change was less than one unit and is not visible to the human eye (6). A ten day delay in the establishment of CA resulted in a 10% loss in firmness even though the apples were stored at 1C during this ten day period.

'Jonagold' apples stored in CA at 1% $O_2$ and 1% $CO_2$ were superior in quality to apples stored at 2% $O_2$ and 3% $CO_2$. Apples stored at the lower atmospheres were firmer with a higher acid content than the apples stored at the higher atmospheres. Although a storage atmosphere of 1% $O_2$ and 1% $CO_2$ has not the recommended storage (12) and would be more difficult and costly to maintain than 2% $O_2$ and 3% $CO_2$; the increased firmness (2.4 N) and acid retention might produce superior quality apples.

Increased storage (50 to 100 days) and ripening (0 to 7 days) resulted in lower quality apples from CA storage (Table 4). Firmness and acids were reduced with increased storage and ripening time. SSC increased as storage progressed from 50 to 100 days, but decreased as ripening time progressed from 0 to 7 days. This decrease in SSC as ripening time progressed may be a sample error. Other research (4) has noted increased SSC in apples as ripening progressed. There was a change in peel color (lower a* and b* values) as storage and ripening time progressed, but this change was slight and not visible to the human eye due to the small change in hue values. No change in flesh color was evident in relation to storage time, but there was a change due to ripening. After 7 days of ripening the flesh color of 'Jonagold' was darker and more yellow (lower L* and hue).

There was a strong relationship between starch index and ripening in both RA and CA stored apples, and between storage and ripening time in RA apples when firmness was considered (Table 5). Firmness decreased in both RA and CA apples during a ripening time of 7 days. Firmness loss was most severe for apples from RA storage at either starch level; a 20% loss was noted at starch level 2 and a 17% firmness loss was noted at starch index 4. During the same ripening time, apples from CA storage displayed only a 5% loss at starch level 2 and an 8% loss at starch level 4. Regardless, 'Jonagold' apples harvested at a starch index of 4 and placed in RA storage did not maintain an acceptable level of firmness during ripening and displayed a firmness of only 37.9 N.

Firmness loss was also evident for 'Jonagold' apples after 50 and 100 days of RA storage, particularly after ripening. Firmness of apples after 50 days of storage and 7 days of ripening was similar to the firmness of apples after 100 days of RA storage that were not ripened. After 100 days of storage and 7 days of ripening, the firmness values for apples was at an unacceptable level (38.7 N). Apples in CA storage lost firmness between 50 and 100 days, but no change in firmness was evident during 7 days of ripening.

## Conclusions

Jonagold' apples should be harvested at a starch index of 2 for either RA or CA storage. Quality of 'Jonagold' apples stored in excess of 50 days in RA storage is minimal at best. 'Jonagold' apples harvested at a starch index of 2 maintained acceptable quality for 120 days of CA stor-

age. Harvesting at a starch index of 4 and then storing in CA resulted in a rapid decline in quality attributes. Storage beyond 120 days was not possible when quality is considered. CA storage atmosphere should be established as soon as possible after harvest. A delay in time to establish CA can result in extreme quality loss. The best storage atmosphere for 'Jonagold is 1% $O_2$ and 1% $CO_2$.

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## BA — Apple Thinning Pn and CHO

BA thinned and increased apple fruit size and accentuated naturally occurring waves of fruit abscission and enhanced translocation of sorbitol from leaves to fruit when applied to the fruit but not when applied to the leaves. Pn was decreased and respiration increased when temperature following BA was 30° C with no effect of temperatures of 20° C. Total non-structural CHO, total soluble sugars, starch in leaves decreased dramatically over the 12-13 day treatment period regardless of treatment but BA increased the decrease further. Abscission fruit had higher CHO levels than persisting fruit regardless of BA application. Authors concluded BA thins fruit, at least in the past, by increasing dark respiration and decreasing Pn. From Yuan and Greene. 2000. J. Amer. Soc. Hort. Sci. 125(2):169-176.