Responses of ‘McIntosh’ Apples to Low Oxygen Storage

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Abstract. Storage of ‘McIntosh’ apples (Malus domestica Borkh.) in low O₂ atmospheres (1.5% CO₂ + 1.0% O₂) maintained fruit firmness by an average of 0.86 kg over 40 grower lots, compared with the same fruit stored in conventional controlled atmospheres (5% CO₂ + 2.8% O₂). Low O₂ storage resulted in fruit which were higher in titratable acids and were significantly crisper, more acid, and juicier to sensory panelists. Fruit maturity at harvest was a significant factor in determining the losses of firmness and titratable acids in low O₂ storage.

Firmness loss of apples in CA storage has been significantly reduced experimentally at storage O₂ levels of 1.0–1.5% rather than the presently recommended O₂ levels of 2.5–3.0% (2, 12). For ‘Cox’s Orange Pippin’ apples stored in <0.7% CO₂ + 1.0% O₂ in England, storage life was extended and fruit texture was better maintained than for apples stored in 5% CO₂ + 3% O₂ (7). However, these workers suggested that storage O₂ concentrations must be controlled within ±0.1% when held at 1.0% O₂ to prevent alcohol accumulation (7). Preclimacteric ‘McIntosh’ apples have also retained texture and titratable acidity better in 1.5% CO₂ + 1.0% O₂ storage than in 5% CO₂ + 3% O₂, without alcohol accumulations and fruit damage in either modified atmosphere (5).

Smock (11) stated that optimal O₂ levels for CA storages determined in small experimental chambers may not be extrapolated to large-scale applications. The present study investigates the effects of a low O₂ atmosphere applied in a commercial-sized storage chamber on storage and post-storage responses of ‘McIntosh’ apples from a range of orchard locations and fruit maturities. Fruit characteristics were determined by in vitro tests and by sensory evaluations. The effects of fruit maturity on post-storage response of ‘McIntosh’ were further investigated in experimental 23 kg sample size lots.

Materials and Methods

Commercial storage trial. Duplicate samples of 23 kg each were harvested from 40 randomly selected commercial orchards. A subsample of 20 fruits was removed at harvest and fruit firmness (opposite sides tested with BALLAUF penetrometer), starch-iodine index, and percentage of dark seed color were determined. A further 10 fruit per orchard were placed in airtight polyethylene jars; air flowed through these jars at 1.2 l/hr at 21°C, and ethylene evolution was determined by gas chromatography of the effluent air.

Of each pair of samples from the 40 orchards, 1 was placed in either a 360,000-kg storage held at 5.0 ± 0.3% CO₂ + 2.8 ± 0.3% O₂ or a 23,000-kg storage held at 1.5 ± 0.3% CO₂ + 1.0 ± 0.3% O₂ at 2.8 ± 0.5°C. All fruit was cooled to 2.8°C within 24 hr of harvest and O₂ removal was initiated 7 days after the initial sample was collected. The desired O₂ levels of 2.8 and 1.0% were established at 7 and 16 days after room closure by catalytic combustion and N₂ flushing, respectively. Storage O₂ and CO₂ levels were maintained by venting to the air outside and dry lime scrubbing (5), respectively.

After 29 weeks of storage, 20 fruit were removed and fruit firmness, soluble solids (refractometric analysis of juice) and titratable acidity (titration of 2 ml of juice diluted with 25 ml distilled H₂O, with 0.1 N NaOH) were determined. The remaining fruit were held at 20°C and 85% relative humidity for 7 days and

the above determinations were repeated. One hundred fruit which had been held for 7 days at 20°C were examined for coreflush, superficial scald and internal breakdown.

Sensory evaluation. Panelists were trained to use an unstructured rating scale to evaluate the following apple characteristics: skin texture quality, cultivar flavor quality, juiciness, flesh texture quality, and overall acceptability. During the training sessions the scale anchor points were agreed upon by the panelists. Examples of the extremes (Table 3) of the scales and intermediate points were presented during training sessions. The descriptive terms used during training sessions and for verbal anchors were selected from the literature (1, 10) and developed by the panelists.

Twenty uniform apples were removed and examined immediately after storage and 20 more were examined after an additional 7 days at 20°C and 85% relative humidity. The apples were washed, dried and brought to 21°C room temperature prior to presentation.

Samples from the 40 orchards were segregated into 3 categories (textures) according to firmness at harvest. A series of taste panels, with 9 panelists each, were arranged according to a split-split split plot design. Main plots were formed with 4 cycles of sessions X 3 replications in a Youden Square arrangement. Each sub-plot consisted of a 3 x 3 Latin square with Panelists and Sessions forming the rows and columns, respectively. One orchard within each texture category was randomly assigned to each panelist. Within each session, each panelist evaluated 2 paired samples (1 at each storage atmosphere) from 2 texture categories (4 apples in all). Over the 3 sessions within each cycle (row in the 3 x 3 Latin square) each panelist observed each of the 3 possible pairs from the 3 texture categories.

Maturity study. A 23-kg sample of 'McIntosh' apples was harvested from across each of 5 trees (replicates) within a commercial orchard. A subsample of 20 fruits was removed for firmness, titratable acidity and soluble solids determinations and a further 10-fruit sample was selected for determination of C2H4 evolution using the previously described method. The fruit at each of 5 maturities (harvest dates in Table 5) were cooled overnight to 2.8°C and the storage chamber was sealed. The storage was then flushed with N2 to reduce the storage O2 to approximately 1% after which O2 was controlled (±0.3%) by venting to outside air and CO2 was controlled at 1.5 ± 0.3% by static lime scrubbing (5). The fruit were removed after 25 weeks of storage, and firmness, titratable acidity, and soluble solids were determined on a 20-fruit subsample immediately after storage and after a 7-day incubation at 21°C and 85% relative humidity. The incidence of coreflush, internal browning and internal breakdown was determined on 100 fruits after 7 days of incubation.

Results

Commercial storage of 'McIntosh' apples in low O2 (1.5% CO2 + 1.0% O2) resulted in significant firmness retention of 0.86 kg after storage and 1.03 kg after 7 days at 20°C compared with apples stored in conventional CA (5.0% CO2 + 2.8% O2) (Table 1). The slope of firmness retention line after storage was significantly different from equality (t = -6.05**) in Fig. 1 indicating that the advantage of low O2 storage was less for firmer apples. However, the slope of the line determined after 7 days at 20°C was not significantly different from equality (t = 1.0NS, in Fig. 1), indicating that the advantage was constant over firmness levels. Apples stored in low O2 atmospheres had significantly higher titratable acids levels after storage and after holding at 20°C than apples stored in conventional CA (Table 1). However, soluble solids levels in apples stored in the 2 atmospheres were significantly different only when determined after 7 days at 20°C. Maturity indices determined at harvest were not highly correlated with fruit firmness determined after storage (Table 2).

Sensory evaluations indicated no significant storage atmosphere effect on the quality of skin texture or fruit flavor when examined after storage and after 7 days at 20°C (Table 3). Fruit stored in low O2 atmospheres were crisper and more acidic after storage and after holding at 20°C than fruit stored in conventional CA. After 7 days at 20°C, fruit stored in low O2 were juicier and more acceptable than fruit from conventional CA. The greater acceptability was probably due to loss of crispness by conventionally stored fruit during the holding period.

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Table 1. Fruit firmness, titratable acidity and soluble solids contents of 'McIntosh' apples stored in commercial 1.5% CO2 + 1.0% O2 and 5.0% CO2 + 2.8% O2 atmospheres at 2.8°C for 29 weeks.

<table>
<thead>
<tr>
<th>Storage atmosphere</th>
<th>Fruit firmness (kg)</th>
<th>Titratable acidity (mg malic/100 ml juice)</th>
<th>Soluble solids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 + 1.0</td>
<td>6.58</td>
<td>5.43</td>
<td>11.41</td>
</tr>
<tr>
<td>5.0 + 2.8</td>
<td>5.72</td>
<td>4.40</td>
<td>11.23</td>
</tr>
<tr>
<td>S.E.D. (n = 40)</td>
<td>0.06</td>
<td>0.05</td>
<td>NS</td>
</tr>
</tbody>
</table>

Significance: ***, **, *, NS. (Significance levels: 5% (**), 1% (***), 0.1% (****).)
Table 2. Correlation coefficients between maturity indices and fruit firmness after storage, with sd along diagonal.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Firmness(^a)</th>
<th>Starch index</th>
<th>Seed color</th>
<th>Max.(^b) C(_2)H(_4)</th>
<th>Firmness(^a) conventional CA</th>
<th>Firmness(^a) low O(_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firmness (H)(^c)</td>
<td>.29</td>
<td>.29</td>
<td>.29</td>
<td>.29</td>
<td>.29</td>
<td>.29</td>
</tr>
<tr>
<td>Starch index</td>
<td>-.55**(^d)</td>
<td>1.17</td>
<td>.28</td>
<td>20.41</td>
<td>-5.1**</td>
<td>2.61</td>
</tr>
<tr>
<td>Seed color</td>
<td>.03</td>
<td>.28</td>
<td>20.41</td>
<td>.51**</td>
<td>.46</td>
<td>.56</td>
</tr>
<tr>
<td>Max. C(_2)H(_4)(^e)</td>
<td>.36*</td>
<td>-.39**</td>
<td>-.33*</td>
<td>.45**</td>
<td>.37**</td>
<td>.70**</td>
</tr>
<tr>
<td>Firmness, conventional CA</td>
<td>.40**</td>
<td>-.31*</td>
<td>-.33*</td>
<td>.45**</td>
<td>.37**</td>
<td>.70**</td>
</tr>
<tr>
<td>Firmness, low O(_2)(^f)</td>
<td>.43**</td>
<td>-.44**</td>
<td>-.35*</td>
<td>.41**</td>
<td>.70**</td>
<td>.56</td>
</tr>
<tr>
<td>Mean</td>
<td>7.36</td>
<td>4.37</td>
<td>32.50</td>
<td>6.75</td>
<td>4.95</td>
<td>5.52</td>
</tr>
</tbody>
</table>

\(^a\)Fruit firmness at harvest
\(^b\)Days to maximum C\(_2\)H\(_4\) climacteric production
\(^c\)Fruit firmness after storage in 5.0% CO\(_2\) + 2.8% O\(_2\)
\(^d\)Significant at 5% level (*) or 1% level (**) or nonsignificant (NS).

The incidence of storage disorders was low and sporadic which precluded statistical analysis. However, 8 orchard lots from conventional CA had an average incidence of 12% coreflush while no coreflush was observed in fruit from the low O\(_2\) storage. The number of lots showing internal browning (10 lots) and breakdown (4 lots) was identical in each of the 2 storages. Scald was not observed on fruit from either storage.

The minimum firmness loss during storage occurred for the fruit collected at the second and third harvest (Fig. 2), when C\(_2\)H\(_4\) evolution was first detected. Maturity was negatively correlated with firmness loss during poststorage keeping period (Fig. 2). Maximum titratable acid retention after storage and shelf life approximated the second harvest date, while fruit firmness was lowest and soluble solids levels were highest at the most advanced maturity for all examinations (Table 4). Senescent breakdown, determined after storage and 7 days at 20°C, was evident (avg 10%, n = 5) in fruit from the final picking only.

**Discussion**

Commercial low O\(_2\) storage tended to maintain fruit firmness of those apples which are least firm immediately after storage. However, after 7 days at 20°C the effect of low O\(_2\) storage was constant over fruit firmness levels. The commercial application of low O\(_2\) storage confirms the beneficial effect on fruit firmness and titratable acids previously reported for 'Turley' (12), 'Delicious' (2), 'Cox's Orange Pippin' (7), and 'McIntosh' (5) apples. There was no evidence of increased incidence of disorders as found by Sharples et al. (9), although coreflush may be reduced in low O\(_2\) atmospheres.
Table 4. Effects of harvest date on firmness, titratable acidity retention and on soluble solids levels in 'McIntosh' apples stored in 1.5% CO$_2$ + 1.0% O$_2$ at 2.8°C for 25 weeks.

<table>
<thead>
<tr>
<th>Harvest date</th>
<th>At harvest</th>
<th>After storage</th>
<th>After storage + 7 days at 21°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Firmness (kg)</td>
<td>Titratable acidity (mg malic/100 mls)</td>
<td>Soluble solids (%)</td>
</tr>
<tr>
<td>Sept. 10, 1979</td>
<td>8.09</td>
<td>865</td>
<td>10.2</td>
</tr>
<tr>
<td>Sept. 15, 1979</td>
<td>7.81</td>
<td>876</td>
<td>10.3</td>
</tr>
<tr>
<td>Sept. 21, 1979</td>
<td>7.44</td>
<td>797</td>
<td>11.9</td>
</tr>
<tr>
<td>Sept. 27, 1979</td>
<td>7.04</td>
<td>784</td>
<td>11.9</td>
</tr>
<tr>
<td>Oct. 2, 1979</td>
<td>6.91</td>
<td>690</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Significance:
- L = linear
- Q = quadratic
- C = cubic
- Qt = quartic

Minimum firmness loss and maximum titratable acids retention in storage depended on fruit maturity. This observation corresponds with the requirement of optimum maturity for storing 'Jonathan' apples in conventional CA (6) and may support the trend described by Knee (4) for 'Bramley's Seedling'.

'McIntosh' apples appear to have a wider tolerance for O$_2$ control than 'Cox's Orange Pippin', 1.0% ± 0.1%, (7). Unpublished data (Lidster) have determined that 'McIntosh' apples are able to withstand storage O$_2$ levels of 0.5 ± 0.2% (with 0.0 or 1.0% CO$_2$) for 29 weeks at 2.8°C without significant accumulation of acetaldehyde or ethanol in the storage and without low O$_2$ injury to the fruit. The range for O$_2$ control for commercial 'McIntosh' storage at 1.0% O$_2$ may be as large as ± 0.5%, which is within most present CA storage limits of control.

Fruit from low O$_2$ storage were significantly firmer than those from conventional CA immediately after storage and a shelf life period. This suggests that low O$_2$ storage of 'McIntosh' may maintain fruit quality of apples and prolong the expected shelf life. Higher titratable acid and firmness retention should reflect longer storage life as the loss of firmness and acid effectively limits the storage life of apples in conventional CA (3, 8).

The present study has shown that storage of 'McIntosh' apples in 1.0% O$_2$ has substantial commercial benefits of improving fruit quality over present CA recommendations (5% CO$_2$ + 3.0% O$_2$). Conventional airtight CA storages with static lime scrubbers and adjustable venting for O$_2$ control may be adapted for 'McIntosh' apples without major alterations and sophisticated mechanical O$_2$ control to achieve the effects of low O$_2$ storage without apparent increased incidence of disorders.

**Literature Cited**