The New York fruit industry is very familiar with the new storage technology based on SmartFresh™. However, another storage technology has become available within the last several years. The technology, known as Dynamic Controlled Atmosphere (DCA) storage, which is commercially available as HarvestWatch™, detects the responses of fruit to low O2 in the storage atmosphere. (Using DCA it is possible to maintain O2 at lower levels and better maintain product quality compared with ‘safer’ atmospheres necessary for standard or ultra low O2 CA storage."

Depending on the storage operation, a number of HarvestWatch systems, each containing six fruit (Figure 2), are used to monitor responses of fruit to the storage environment. These monitors are connected to a computer control system so that the storage operator can adjust O2 levels in response to any fluctuations in the fluorescence signals. These changes may occur not only because of deliberately applied low O2 stress, but also because of changes in fruit condition over time. Therefore, HarvestWatch can be used to monitor changes either resulting from natural fruit senescence or those that may result from problems with equipment malfunction. In practice, a buffer of about 0.2% O2 is added to the level at which a fluorescence response is detected in order to provide a safety margin.

An important feature of DCA is that it is a chemical-free technology that meets the requirements for organic produce. Although 1-MCP has a non-toxic mode of action, negligible residue, and is active at very low concentrations, it is not naturally occurring post-harvest chemical.

The New York apple industry relies heavily on controlled atmosphere (CA) storage in addition to temperature and relative humidity control to maintain fruit quality during storage and to ensure visually appealing, flavorful, and healthy apples are available to the consumer. In addition, SmartFresh™ technology, which is based on the ethylene inhibitor 1-methylcyclopropene (1-MCP), is now used extensively by New York storage operators. The advantage of SmartFresh™ is that it helps maintain quality not only during storage, but also during the entire marketing chain as it prevents softening at warmer temperatures.

Initially, CA storage technology was restricted to standard or traditional CA storage in which O2 in the storage atmosphere decreases over time, a point is reached when the fluorescence signal increases (Figure 1). This increase is a signal that the fruit is under low O2 stress. In response, the O2 level around the fruit can be raised. Relief from stress is reflected in a decrease of the fluorescence signal.

Widening a Narrow Base—Collection Expeditions to Central Asia, the Apple’s Ancestral Home

Silk Road traders and their predecessors started the spread of apples from Central Asia to other parts of the world. But the seeds they carried likely represented a narrow genetic sampling. That’s probably why today’s American domestic apples have a fairly narrow genetic base that makes them susceptible to many diseases.

From 1989 to 1996, the USDA sponsored expeditions to Central Asia to collect seeds and tree samples (scions) from unique apple trees growing in natural forests. Seven expeditions were completed from 1989 to 1999. Four of them were to Central Asia to collect wild apple Malus sieversii, the main progenitor of the commercial apple, M. x domestica.

The Experiment Station’s Herb Aldwinckle was a participant on the first trip to Central Asia in 1989. Philip Forline, who is the curator of the national apple collection, was a member of seven of the trips, including four to Central Asia to collect apple collection, conserve it, and, after evaluation, distribute it to breeders and geneticists worldwide. Other trips were to China (Sichuan, Russian, and Turkish sectors of the Caucasus region, and Germany. He recalls the expeditions as hard work. Herb joined Phil also on the trips to Kazakhstan and Turkey. Often, the only way of getting to remote mountain areas was by helicopter, longikes, or half-day-long jeep rides down bumpy, dusty roads. What we collected made possible our re-creation of Kazakhstan, China and the Caucasus region here in Geneva. All that is now effort bearing fruit, literally and scientifically. We tapped millions of years of adaptations to improve today’s apple.

The trips resulted in at least a doubling of the known genetic diversity of apples. In all, the scientists returned from Central Asia with 949 apple tree accesses. Most of the specimens were brought here as seed, but 50 were cataloged as ‘elite clones’—graffins of the original trees. The seeds gathered on the trips increased PGRU’s apple collection by 1,140 samples, to over 3,900. The visits to Kazakhstan and Kyrgyzstan especially were of interest in particular—which is likely the center of origin or ancestral home of familiar domestic apples (Malus x domestica) such as Red Delicious, Golden Delicious, and McIntosh.

The most successful strategy to date is based on real-time sensing of fluorescence changes using a Fluorescence interactive response monitor (FIRM, Satlantic inc., NS, Canada). This technology is patented and has been marketed under the name HarvestWatch™ since 2002 (Delon et al., 2004a). There are about 120 apple storage facilities using HarvestWatch technology worldwide, and this number is increasing; most are in Northern Italy but units are operating in Germany, the Netherlands and Washington State (R. Prange, personal communication).

Chlorophyll fluorescence can be used to measure stress in the apple fruit. As the O2 level in the storage environment decreases over time, a point is reached when the fluorescence signal increases (Figure 1). This increase is a signal that the fruit is under low O2 stress. In response, the O2 level around the fruit can be raised. Relief from stress is reflected in a decrease of the fluorescence signal.

Depending on the storage operation, a number of HarvestWatch systems, each containing six fruit (Figure 2), are used to monitor responses of fruit to the storage environment. These monitors are connected to a computer control system so that the storage operator can adjust O2 levels in response to any fluctuations in the fluorescence signals. These changes may occur not only because of deliberately applied low O2 stress, but also because of changes in fruit condition over time. Therefore, HarvestWatch can be used to monitor changes either resulting from natural fruit senescence or those that may result from problems with equipment malfunction. In practice, a buffer of about 0.2% O2 is added to the level at which a fluorescence response is detected in order to provide a safety margin.

important feature of DCA is that it is a chemical-free technology that meets the requirements for organic produce. Although 1-MCP has a non-toxic mode of action, negligible residue, and is active at very low concentrations, it is not naturally occurring post-harvest chemical.

Dynamic Controlled Atmosphere (DCA) Storage

Dynamic Controlled Atmosphere (DCA) uses technologies that allow sensing of fruit responses to low O2. Therefore, instead of maintaining the ‘safe’ 2-3% O2 levels which are higher than optimum to obtain maximum benefits, it is possible to lower the O2 levels over time in response to changes in fruit metabolism. By lowering the O2 levels in the storage atmosphere to the lowest possible before anaerobic respiration produces ethanol, ripening can be delayed more effectively than in standard ULO CA storage.

Responses of fruit to low O2 can be detected by measuring ethanol production, fruit respiration, and chlorophyll fluorescence. Dynamic Controlled Atmosphere Storage – A New Technology for the New York Storage Industry?

Chris B. Watkins
Department of Horticulture
Cornell University, Ithaca, NY
The Apple Collection in Geneva, NY:
A Resource for The Apple Industry
Today and for Generations to Come

Located at the New York State Agricultural Experiment Station at Geneva, NY is a little known great public resource—the largest apple collection in the world. Also little appreciated is how critical this collection is for the future of the industry. More and more of the new apple and apple rootstock varieties that we have today come from breeding programs that have utilized the genetic resources being maintained and characterized in these apple collections.

The National Apple Collection

The national collection of apples at Geneva, NY was assembled and is maintained by Agricultural Research Service of the USDA, has thousands of varieties. The national collection of apples, the main progenitor of the commercial apple collected from the wild apple forests of Central Asia (Kazakhstan in particular) have genetic resistance to diseases that may help apple breeders breed new varieties and rootstocks that can resist against diseases. This genetic makeup may revolutionize the nation—and perhaps the world—apple industry.

Figure 2. The HarvestWatch™ fluorescence system showing the fluorescence interactive response monitor (FIRM) unit affixed in an upper sampling kernel (center), apples in the bottom kernel (right) and a central hub (left). Before storage, apples are placed in the bottom kernel over which the upper kernel housing the FIRM unit is securely fastened. In storage, the FIRM units are wired to the hub which controls the interaction of electronic signals from a central computer to each attached FIRM device. (Reproduced with permission of Dr. E.K. Prange).

Figure 3. Effect of oxygen concentration on O$_2$ consumption and CO$_2$ production (from Prange, Bishop and DeLong, 2005).

however, because the maximum storage period tested was only six months, a short period of time for scald control. Although scald was eliminated in ‘Cortland’ and ‘Delicious’ after nine months of DCA storage plus a seven-day shelf life in a Canadian study (DeLong et al., 2004a), subsequent research showed that DCA-stored fruit with no scald at removal can develop varying amounts of scald at shelf temperature (DeLong et al., 2007). We have not carried out research in New York, and therefore no research that directly compares DCA and 1-MCP treated apples is available.

In Nova Scotia, two studies show that scald control with either technology is limited. Scald development in ‘Cortland’ and ‘Delicious’ apples was markedly reduced by DCA compared with standard controlled atmosphere (SCA) (Table 1). However, the benefits of DCA for Cortland apples were still not acceptable from a commercial perspective, only after four months of storage. Control of...
Table 1. Superficial scald incidence in ‘Cortland’ and ‘Delicious’ apples stored in standard controlled atmosphere (SCA) and dynamic controlled atmosphere (DCA) storage for 4 and 8 months plus a 7-day day shelf life (modified from DeLong et al., 2007).

<table>
<thead>
<tr>
<th>Storage time (months)</th>
<th>Cortland</th>
<th>Delicious</th>
<th>SCA</th>
<th>DCA</th>
<th>SCA</th>
<th>DCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>68</td>
<td>18</td>
<td>10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>90</td>
<td>43</td>
<td>23</td>
<td>10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Superficial scald incidence in ‘Redcort Cortland’ apples either untreated or treated with SmartFresh (0.9 ppm 1-MCP) and stored in standard controlled atmosphere storage for 3, 6 and 9 months plus a 7 day shelf life (modified from DeLong et al., 2004b).

<table>
<thead>
<tr>
<th>Storage time (months)</th>
<th>Superficial scald (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Un treated</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>6</td>
<td>67</td>
</tr>
<tr>
<td>9</td>
<td>68</td>
</tr>
</tbody>
</table>

Scald can also be lost in SmartFresh-treated apples. In another Canadian study, ‘Redcort Cortland’ apples were either untreated or treated with SmartFresh and stored in CA for up to nine months. The results show that very good control of scald was obtained for six months of storage, but by nine months, commercially unacceptable levels of scald were present (Table 2). The marketplace is extremely sensitive about scald and any signs of the disorder can result in rejection of loads. DCA is apparently no more effective than SmartFresh in controlling scald in some varieties. While scald can be controlled by SmartFresh in varieties such as ‘Cortland’, we have found that this control can be variable. Loss of scald control is associated with release of fruit from inhibition of ethylene production.

Another interesting feature of DCA is that, unlike 1-MCP, it appears to not significantly increase the risk of external CO2 injury. Increased risk of CO2 injury is a feature of 1-MCP treatment, especially with ‘Empire’ as reported in an earlier NY Fruit Quarterly article (Bazzafurbi et al., 2006). CO2 injury is also controlled by DPA when it is applied to inhibit scald development (Watkins and Nock, 2007). Because some of our New York ‘Empire’ blocks produce fruit that are highly sensitive to CO2 injury, a cautious approach may be warranted, with at least a proportion of fruit in the rooms being DPA-treated. The bottom line is that DCA cannot be recommended as a non-chemical scald control method in New York without further research. DPA treatment of fruit would still be essential to avoid risk of scald development in highly susceptible varieties such as ‘Cortland’.

Fruit firmness. Firmness is a critical factor in marketing of apples. Control of softening, not only during storage but through the entire marketing chain, has been a major reason for the rapid uptake of SmartFresh technology. The same two Canadian studies have been used to compare the effects of DCA and SmartFresh. It should be recognized that while one variety ‘Cortland’ is in common, there are limitations to direct comparisons of studies carried out in different years.

Table 3 shows a comparison of standard CA and DCA on firmness of ‘Cortland’ and ‘Delicious’ apples before and after a shelf life period. ‘Cortland’ apples remained much firmer in DCA than in SCA storage, especially at the longest storage period of eight months. However, the fruit softened markedly during the shelf life period of...
seven days, and were firmer in the DCA-stored fruit than in the SCA only after eight months. Benefits of DCA on firmness, both immediately after storage and after a seven-day shelf life were much greater for ‘Delicious’ apples. In the case of SmartFresh-treated ‘Cortland’ apples, no data about the shelf life period effects were provided (Table 4), but SmartFresh-treated apples were much firmer, even at nine months storage plus a seven-day shelf life, than shown for DCA-stored fruit in Table 3.

Table 3. Firmness (lb) of ‘Cortland’ and ‘Delicious’ apples stored in standard controlled atmosphere (SCA) and dynamic controlled atmosphere (DCA) storage for 4 and 8 months plus 0 or 7 days of shelf life (modified from DeLong et al., 2007).

<table>
<thead>
<tr>
<th>Storage time (months)</th>
<th>Firmness (lb)</th>
<th>CORTLAND</th>
<th>DELICIOUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 + 0d</td>
<td></td>
<td>14.7</td>
<td>15.5</td>
</tr>
<tr>
<td>4 + 7d</td>
<td></td>
<td>11.4</td>
<td>17.3</td>
</tr>
<tr>
<td>8 + 0d</td>
<td></td>
<td>11.9</td>
<td>14.1</td>
</tr>
<tr>
<td>8 + 7d</td>
<td></td>
<td>10.2</td>
<td>11.8</td>
</tr>
</tbody>
</table>

Table 4. Firmness (lb) of Red Chief Cortland apples either untreated or treated with SmartFresh (0.9 ppm 1-MCP) and stored in standard controlled atmosphere storage for 3, 6, and 9 months plus a 7 day shelf life (estimated from graphical data DeLong et al., 2004b).

<table>
<thead>
<tr>
<th>Storage time (months)</th>
<th>Firmness (lb)</th>
<th>Untreated</th>
<th>SmartFresh</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>17.3</td>
<td>17.3</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>12.6</td>
<td>15.5</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>10.1</td>
<td>15.5</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>9.7</td>
<td>15.7</td>
</tr>
</tbody>
</table>

The take home message from these comparisons is that the variety effects on the benefits of DCA technology are probably the most important factor in its success compared with SmartFresh. Control of softening by SmartFresh was more persistent than DCA for ‘Cortland’, while post-storage softening of ‘Delicious’ was well controlled by DCA storage. Other studies indicate that post-storage softening of DCA-stored fruit may be lower than for standard CA-stored fruit of ‘Granny Smith’ and other varieties. However, the paucity of published information about other varieties and factors such as fruit maturity on the effectiveness of DCA needs to be addressed in order for the New York storage industry to make good decisions about the value of the technology.

Conclusions

An advantage of DCA is that it is a non-chemical treatment that meets requirements for organic produce or when post-harvest chemical use is not permitted. However, DCA storage requires high quality CA rooms and electronic atmosphere control, and is less flexible than 1-MCP, which can be applied in rooms, tents, and containers. DCA- and 1-MCP-based technologies slow softening, including during shelf life periods, resulting in better quality produce for the consumer. Both technologies inhibit development of superficial scald, but their effects on softening and scald are affected by variety. Limited scald control by either technology, at least for the limited number of varieties tested, suggests that neither provides a risk-free replacement for DPA for highly scald-susceptible varieties.

In summary, DCA technology is an important addition to the arsenal of the storage operator, but like SmartFresh, it has its strengths and weaknesses. More research on DCA for the New York industry is warranted.

**Acknowledgements**

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**References**


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