OBSERVATIONS ON HARVEST MATURITY AND STORAGE OF APPLES AND PEARS

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There has been much discussion about the current state of knowledge about desirable controlled atmosphere (CA) storage regimes for Washington grown apples and pears. Unfortunately, there is no working group that meets to formulate recommendations for CA storage. The following are my observations gathered from published research, formal and informal scientific meetings, recommendations from other fruit growing regions, and my personal experience with the Washington fruit industry. They are my best 'educated' guesses as to how to store Washington grown apples and pears.

PEARS

As guideline for harvest maturity, Bartlett pears should be considered mature to harvest starting at 19 lbf for CA and continuing to 17 lbf for short-term storage. Anjou pears start at 15 lbf for CA and continue to 13 lbf. Bosc pears start at 16 lbf for CA and continue to 14 lbf. In all pears, it is important to watch the starch level, because in certain seasons firmness will remain high for a time while the starch content changes. This starch change indicates a movement in maturity.

Pears must be at storage temperature before the oxygen is lowered.

Research by Dr. Steve Drake (USDA-ARS) indicates that under certain conditions skin marking has been associated with paper with a high concentration of oil.

Anjou pears should be stored at all times with the oxygen at least 1% higher than the carbon dioxide, especially when the fruit are held at 31.5 or 32 °F. Many storage operators use 1.5 to 2.0% O_2 with less than 0.5% CO_2 at 32 ºF.

There has been research that pears stored at higher temperatures (34 °F) can tolerate higher CO_2 levels. In Steve Drake's experiments with Anjou pears over several years, fruit stored with CO_2 levels 1% above the oxygen level (at 34 °F) had no internal browning, were greener, and had less skin marking than fruit stored at low CO_2 levels.

On another track, Dr. Paul Chen's work has shown that Anjous can be stored at very low levels of oxygen initially (0.5 %) and raised stepwise to the standard regime over several months. This regime has controlled storage scald without Ethoxyquin. Low oxygen skin marking has developed on some fruit, thus the low oxygen shock should not be prolonged.

APPLES

When thinking about CA for apples I divide the varieties into two types: those that are tolerant of high CO_2 and those that are not. Obviously, this is a broad generalization.

Gala and Golden Delicious

Gala and **Golden Delicious** are the varieties that I place in the CO_2 tolerant category. These varieties also benefit from rapid reduction of atmosphere. Rapid CA is valuable in that it helps retain fruit firmness and acidity better than slowly established CA on these varieties. Thus, fruit at moderate temperatures can be placed in a low oxygen environment rapidly without problems.

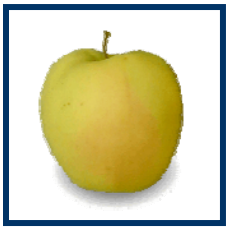
How rapid is rapid? This question has taken on new meaning as currently available equipment can remove oxygen more rapidly than ever before. Ten years ago, 'rapid CA' was defined as having the first harvested fruit in a room down below 3% oxygen within 7 days. Now we are talking about the possibility of filling several rooms each day and having them down to 3% oxygen within hours of harvest! Regardless of how quickly the equipment can pull down the atmosphere, fruit with core/flesh temperatures greater than 60 °F should be cooled to at least 50 ºF prior to lowering the oxygen level.

Non-spur Golden Delicious apples should be harvested at 16.0 lb pressure with a starch rating of 2.7 (1 to 6 scale), soluble solids at 11.5%, and acidity of 0.700% if they are to be held in long-term CA. The rate of change as well as the absolute numbers should be considered. When the firmness of Goldens falls 0.5 lb in one week, the soluble solids increase 0.5%, or starch increases by 0.2 units, the fruit are ripening and harvest should commence.

Current conditions do not permit profitable marketing of Goldens with green skin. Skin color on Goldens is often a reflection of the amount of nitrogen in the tree. Leaf nitrogen levels above 2.15% will result in soft Goldens with very green color. Only fruit from trees with moderate nitrogen levels should be selected for CA. There is a temptation to allow Goldens to hang longer to promote the change in skin color; these fruit are not suitable for CA.

Gala and Golden Delicious can be stored as low as 1.0% oxygen with CO_2 levels up to 2.5% at 34 °F. As the temperature is lowered below this point, the oxygen should be raised. Regular storage should be at 32 °F.

Ginger Gold



Ginger Gold is a popular new early season variety. We worked with Ginger Gold harvested in 2001 then stored them in air at 32 ºF. We removed a sample at regular intervals and found that both the out of storage firmness and the shelf life declined very rapidly. Even at harvest they can lose as much as 4 lbf in 7 days at 70 ºF. Ginger Gold apples stored for 65 days developed off flavors, aromas and flesh breakdown. After only 40 days we were seeing some decay. This is a variety that should be packed and shipped, not stored.

Fuji, Braeburn and Granny Smith

Fuji, **Braeburn,** and **Granny Smith** are those varieties that I place in the CO_2 intolerant category. The cells appear to be dense and air circulation around the cells within the fruit is difficult. I include **Rome** in this category.

The flesh temperature should be very close to the storage temperature before the oxygen is reduced. These varieties have a tendency for internal browning (BBD, core flush, etc.), which is associated with the natural predisposition of the apple variety (and other preharvest factors) as well as the storage regime. Delaying the imposition of lower oxygen levels after the fruit reach storage temperature has helped minimize internal browning.

Carbon dioxide should remain well below the oxygen at all times with these varieties. Temperatures should be held slightly elevated during CA storage. For example, fruit stored at 1.5% oxygen should be stored with CO_2 below 0.5% at 34 °F, if the fruit is not overmature at harvest. It is not advisable to store waxed fruit in boxes with polyliners in CA, as this can hinder air circulation within the fruit.

Storage in regular atmosphere can be at 32 °F. with good air circulation.

Pink Lady® Brand Apples

Pink Lady® Brand apples were developed in Australia and have recently been planted here in Washington. According to Dr. Colin Little of Australia, Pink Lady® brand apples grown in Australia mature about 10 days after Granny Smith. Firmness at harvest should be at least 17 lbf. He advises against using Ethrel to hasten maturity of Pink Lady® brand apples because it is very high ethylene producer. Pink Lady® brand apples can be stored in a room with Granny Smith. He suggests a 5 to 7 day temperature pull down with a final temperature at 33 to 34 ºF. The CA regime should be 1.8% O_2 and 0.5% CO_2 at 33 to 34 ºF, thus it is CO_2 intolerant. It is subject to core flush.

It has been reported that in a couple of shipments soft Australian-grown Pink Lady® brand apples arrived in UK markets. The problem of soft fruit has been traced to inadequate fruit mineral status at harvest, as well as advanced maturity. When nitrogen levels are too high (young trees?) and calcium levels are low, then fruit are susceptible inadequate firmness. This may a variety in which fruit mineral analysis could be a useful tool.

Dr. Steve Drake has been looking at Washington grown Pink Lady® brand apples. His information suggests that they hold up well in storage; however there was some internal breakdown after 180 and 210 days in storage when starch levels at harvest were 2 to 3. He has stored Pink Lady® brand apples at 1% O_2 with 1% CO_2.

Pink Lady® brand apples grown in Italy developed scald and flesh browning following CA storage. Scald risk decreases with maturity at harvest and with DPA treatment. Flesh browning occurs in more mature apples on fruit from trees with high nitrogen levels and low calcium. When the crop load is heavy and there is a large temperature swing at harvest between day and night, the risk of disorder increases.

The Washington industry reports major problems with the amount of bruising that occurs at harvest so pickers need to be especially careful when harvesting Pink Lady® brand apples.

Jonagold

Jonagold is an apple with Golden Delicious and Jonathon parentage. This very large and tasty apple matures rapidly on the east side of the Cascades and is very subject to heat stress (Bitterpit, etc.) under desert growing conditions. The starch index is used in the eastern United States and Europe for judging maturity. However, under Washington conditions often the starch disappears before the fruit has sufficient red skin color to satisfy commercial markets and often the fruit is left on the tree until it is not suitable for storage. Jonagold is also grown in Western Washington sometimes on land formerly used for pasture. This results in fruit that has poor mineral content and balance.

Field staff must evaluate the suitability of each grower lot of Jonagold apples as part of the storage process. There may be some lots of fruit that are not suited for storage and should be sold immediately.

If a grower lot of Jonagold apples is suitable for storage, our research has shown the importance of rapid cooling and establishment of CA conditions. CA-stored Jonagold apples will have flavor and pressure superior to that stored in RA only if conditions are established rapidly. Even a 5-day delay after harvest results in fruit that is not as good as when rapid CA (2 days) is used. There is little difference between CA and RA stored apples following 100 days when the delay is more than 2 weeks after harvest.

CA storage regimes for Jonagold range from 1% O_2 with 1% CO_2 at 34 ºF in research trials to 1.5% O_2 and 1.5% CO_2 in commercial trials. Washington-grown Jonagold apples deteriorate rapidly in storage and fruit brought out of storage after 120 days are of inferior taste to those stored for a shorter period of time, even in CA.

Red Delicious

Red Delicious is CO_2 tolerant and is tolerant of rapid CA. However, producers have not seen the dramatic positive effects of very rapid CA on Red Delicious that is seen on Goldens or Galas. Storage operators should realize that this fruit softens more rapidly in a bin than on the tree so CA should not be delayed after harvest.

Red Delicious should be harvested at 17.0 lbf with the soluble solids at 10.0%, acidity at 0.270%, with a starch rating of 1.6 (1 to 6 scale) for long-term CA storage. Usually these fruit are postclimacteric with ethylene at 5 to 6 ppm. The rate of change as well as the absolute numbers should be considered. When the firmness of Reds falls 0.5 lbf in one week, the soluble solids increase 0.3%, or starch increases by 0.2 units, the fruit are ripening and harvest should commence.

One caution about timing harvest for Red Delicious is the issue of its susceptibility to storage scald. Storage scald susceptibility decreases with maturity and an increase in cold nighttime temperatures. Scientists have determined the risk of scald decreases as temperatures below 50 °F accumulate within 3 to 4 weeks prior to harvest. Once over 100 degree-day units (hours below

50 °F) have accumulated, scald should not be a problem in long-term CA if Red Delicious is treated with DPA.

Typical storage regimes for CA of non-watercored Red Delicious is 1.5% oxygen and up to 2.0% CO_2 at 32 °F to 34 °F. I have done trials using early season commercially harvested Red Delicious at 0.7% oxygen with good results. This low level of oxygen should never be used on watercored apples, but in some cases can substitute for DPA in controlling scald.

Regular storage is usually at 32 °F or slightly below.

Watercore

Watercored fruit provides a special challenge to storage operators. Experience has shown that Red Delicious with watercore will develop internal browning within 3 months in CA storage, when the watercore is moderate or severe at harvest.

Discussions have revolved around the best way to remove watercore from the fruit. Watercore is liquid sugar/alcohol (sorbitol) that surrounds the cells of the fruit. This interrupts the exchange of gasses (oxygen going into the cells and CO_2 out of the cells) and the fruit develops internal browning. Obviously, the best solution is never to place watercored Reds in CA. However, given the current rigors of marketing, this may be difficult.

I don't know the best way to remove watercore from severely watercored ('pineapple watercore') fruit. On the other end of the scale, slightly affected fruit may respire away the watercore and may not develop internal browning.

A greater risk comes in dealing with moderate watercore. This is fruit with slightly coalesced watercore. Some in the industry believe that by slowing the cooling and/or slowing the process of establishment of CA, one can allow the fruit to respire away watercore. The risk here is that fruit with watercore is already soft, and by delaying CA the fruit will soften further, which shortens the storage life and increases the risk of not being allowed to ship it at all.

Maturity management must come first. Not all fruit is suitable for CA. If a block has developed watercore to a moderate extent the risk of storage injury rises. Storage operators may be willing to take the risk. I doubt that it results in quality fruit for the consumer.

Fuji also develops watercore. It is a positive attribute of Fujis and was selected by the Japanese for this characteristic. However our postharvest experience with Fuji fruit to watercore appears to be different from that of Red Delicious. Trials and industry experience have shown that Fuji with slight or moderate watercore can be stored in CA. Of course, severely watercored fruit will deteriorate in CA storage if stored too long. The fact that Fujis should be cooled prior to the establishment of CA may contribute to the disappearance of watercore after storage. The very firm texture of Fuji at harvest makes it less hazardous to softening.

Drenching

Drenching to prevent storage scald is a subject that also comes up at this time of year. Like everything else, drenching is subject to risks. When drenching, it is very possible to spread spores from infected fruit. Thus, applying DPA to reduce the risk of scald increases the risk of decay. There are very few postharvest fungicides. Most packers will not use Captan due to restrictions in export markets. Thiabendazole (TBZ), the most widely used fungicide is not as

effective as Benlate once was. It has been estimated that as many at 50% of the spores may not be susceptible to control by TBZ.

How can the risk of decay be minimized?

- The greater the number of bins that go through each batch of solution, the larger the risk that decay organisms will accumulate. Therefore, don't extend the number of bins drenched by a batch of solution to beyond the label rate, regardless of the type of filtering system used. Filtering may be an excellent way to keep the solution clean (of dirt) while drenching, but is not a substitute for new solution.
- Don't combine the dirty residue from one tank with that of a fresh tank. Get rid of dirty or spent solutions.
- Check the levels of chemicals on the fruit to be sure that the correct amount is arriving on the fruit. Don't assume that because the solution in the tank is at the correct concentration that the fruit has received the correct amount.
- Are the trucks remaining under the drencher long enough? Don't let the need to turn trucks around be more important than a long enough dwell time under the spray.
- Clean the tanks between batches. Remove all the residual debris.

Which varieties should be drenched? (TBZ should be included in any drench.)

- Many storage operators stopped drenching **Golden Delicious** when they saw burn on fruit from rapid CA. In most blocks they have not seen an increase in decay after storage during years of dry harvest weather. **Galas** are not subject to scald thus they should not be drenched. Some packers have used DPA at 1000 ppm to prevent delayed sunburn but I have no proof this is effective. Drenching increases the risk of decay.
- **Granny Smith** is highly susceptible to scald and should be drenched, regardless of whether the fruit is stored in CA or regular storage.
- The initial industry experience was that when **Fuji** apples were drenched, the incidence of decay was greater than when they were not. Further experience revealed that decay was significant when dirty drench water was used. Reducing the number of bins per drench solution (even below label rate) can be effective in minimizing decay. Studies have shown that DPA can help reduce internal browning. If an operator chooses to drench Fujis, then the fruit should have the stems clipped to reduce stem punctures, pickers should be closely supervised to prevent fruit bruising, and the drench solution should be changed very frequently to minimize the risk of decay. In 1999 season we saw storage scald on some undrenched Fuji apples from long-term CA. Most of the scald was on late harvested fruit from the interior of the canopy—fruit that should not have been placed in CA.

Research we have done on the 2000 and 2001 crops with DPA has shown that Fuji is very sensitive to lenticel marking and chemical burn (see photo). Damage increased as DPA concentration increased, thus no more than 1000 ppm should be applied. Remove bin liners or bubble pads that can trap DPA residue against the fruit. For more information, see *Effects of DPA Drenching on Newer Apple Varieties*

(http://postharvest.tfrec.wsu.edu/EMK2002C.pdf) on the WSU—TFREC Postharvest web site.

- **Braeburn** should be considered for drenching if the solution is carefully monitored at 1000 ppm. Studies have shown that DPA can help reduce internal browning.
- **Pink Lady®** brand apples could be drenched with DPA at 1000 ppm**.** Until 2 years ago there were no incidences of storage scald, but last year scald was reported in many fruit growing regions.
- **Red Delicious** and **Cameo** placed into CA can be drenched at 2000 ppm, unless low oxygen storage is used to reduce the risk of scald (at 0.7% oxygen) for organic apples.

Calcium in the drench solution can assist with the reduction of nutrient related disorders, such as bitterpit. However, the most effective place to apply calcium is in the orchard. Postharvest drenching can do very little to reduce disorders and disposal of chloride under Department of Ecology regulations is a serious problem for many packers.

Organic

Preventing storage scald in organically grown apples is being done in some locations in Washington and in Canada by using very low levels of oxygen in CA storages. The success of this method relies on the relative risk of scald developing. The relative risk is based upon: the variety with Granny Smith being highly susceptible and Golden Delicious being not susceptible; the accumulation of cold temperatures prior to harvest which reduces risk; the maturity of the fruit, with more mature fruit less susceptible and the length of storage.

Canadian storage operators are using 0.7% O_2 with low levels of CO_2 at 33 ºF very successfully with Red Delicious. We tested this system on Red Delicious in a commercial facility for several years with excellent results.

1-MCP

1-MCP, also known as 1-methocyclopropene is a gas that can inhibit the action of ethylene on fruits, vegetables and cut flowers. Dr. Jim Mattheis and others are working to understand how this gas can be used to retain firmness and acidity in apples and pears. The gas will be applied after harvest and sold under the name of 'SmartFresh' by the company 'AgroFresh', a subsidiary of the Rohm and Haas Co. Results on apples show that 1-MCP can help fruit retain firmness and acidity in regular or CA storage, and prevents scald. Apples will also retain skin green color with 1-MCP. Little research has been done on the effect of 1-MCP on apple flavor or on consumer acceptance of 1-MCP treated fruit. It is one of the most exciting advances in crop preservation in recent memory.

IN CONCLUSION

These are my observations and thoughts on the storage regimes for Washington grown apples and pears. Some of these observations may be incorrect, or new information may come to light and change my thinking.

I urge you to check the postharvest web site at: http://postharvest.tfrec.wsu.edu for excellent information on tree fruit postharvest practices. I am interested in your observations; please do not hesitate to contact me.