The art of post-harvest management: Part 1

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Management is the key word here, but what exactly is being managed? Is it the cold store equipment, the room atmosphere or fruit physiology itself? It is the fruit of course.

Orchardists spend five to seven months nurturing fruit whilst on the tree and can spend up to 10 to 11 months managing it whilst in store. To deliver a good eating experience for consumers the dedicated effort spent in obtaining good fruit in the field must continue throughout storage. Only fruit that delivers a good eating experience will meet retailer specifications and drive consumer demand.

Australian fruit growers have invested heavily in technology and techniques to manage fruit well during storage. However, no technology or techniques stay the same forever. I'll now explain some of the tools available to the modern cold storage manager, what and why we use them and what's new in the tool-box.

It has been said that the life of an apple starts at flowering and the death of an apple starts at harvest. Respiration is the degenerative process when an apple stops making carbohydrates and starts using its stored reserves to keep it alive before finally expiring. The art of post-harvest management is to slow down and prolong the respiration process so that when the product is eaten the consumer has a good eating experience. It's not enough just to slow down respiration but we also need to manage the fruit and its environment so that disorders and rots don't also reduce the health or acceptability of the fruit.

How do we best prolong this respiration process?
Like all biological processes, respiration is slowed if temperatures are lowered and the inputs to the process reduced. Hence the traditional tools have been lowering temperatures and restricting the oxygen available for the apples and pears to breathe.

Temperature management

The traditional approach to cooling was to blast the fruit with as much cold air as possible to get it to its end temperature as soon as possible. This requires high capacity cooling equipment with large fans, both which are expensive to buy and to run. The result is that generally they extracted more moisture from the fruit than needed, as well as exacerbating some storage disorders, contributing to poor packout. Apples and pears were traditionally sold on size where weight loss was less important than it is today with weight based grading equipment.

Nowadays, cooling fruit is usually a dynamic process starting with: 1) removal of initial field heat, then, 2) a period of time where the temperature is lowered in a step wise manner to reach, 3) the final storage temperature for the majority of storage life. For example, Pink Lady™ is lowered to 4ºC as soon as possible after harvest, then the temperature lowered by 1ºC each week for 2 weeks (step-wise) for a final storage temperature of 2ºC.

Step-wise cooling is kinder on the fruit – it can go to sleep slowly and this minimises stresses that can lead to skin damage on some varieties. Step-wise cooling is less expensive as refrigeration equipment works for fewer hours at a lower intensity. Less moisture is removed from fruit when it is step-wise cooled and held at warmer temperatures. However, without the use of the ethylene management tool SmartFresh Technology, step wise cooling is not recommended . Likewise, slower cooling and warmer end temperatures may not be appropriate for over-mature fruit or fruit that has experienced a heat wave just prior to harvest.

Cold storage is the greatest energy use for an orchard and it's interesting that savings from storing some varieties warmer and using slower pull down times have coincided with the increase in electricity prices and calls for smaller carbon footprints. It's not often that a problem and a solution coincide!

Atmosphere management.

There are three gases that need to be managed when storing fruit; oxygen (O_2), carbon-dioxide (CO_2) and ethylene. Oxygen is what the apple breathes in during respiration and CO_2 is what it breathes out. The respiration process converts carbohydrates to energy plus water (it's the reverse of photosynthesis which converts CO_2 plus water to carbohydrates plus oxygen). Ethylene is the natural fruit ripening plant hormone produced during respiration that speeds up ripening and then causes fruit to break down and rot, which increases the chance for a seed to be dispersed. Ethylene has been described as 'the great fruit destroyer'.

All three gases interact differently with each of our major fruit varieties and are different for each fruit maturity. This means that management usually has to differ for every room (no one said cold store management was easy!).

Oxygen.
When O_2 is reduced below 8 per cent fruit respiration slows and maintenance of apple quality is prolonged. This is called controlled atmosphere storage (CA) and O_2 levels of 2.5 per cent have been successfully used for many decades. Further reduction to 1.0 to 1.8 per cent or ultra low CA (ULO CA) can give added benefits of prolonged life as well as reducing the incidence of the superficial scald disorder. Ultra low CA was developed in the 1990s when the scald treatment DPA was under review in many parts of the world. Ultra low CA requires very good CA generating equipment, very well sealed cold rooms, good monitoring equipment and good management.

However, there is an increasing risk when lowering oxygen levels below 1 per cent that anaerobic respiration will occur in fruit. Anaerobic respiration is when O_2 is only partially used in respiration and ethanol is produced as a by-product. Alcoholic taints and off flavours develop with flesh discoloration a likely result. The point where anaerobic respiration occurs ranges between 0.8 per cent and 1.8 per cent O_2 and is not a given point for each variety. It depends on the growing season, the fruits physiological sensitivity to low O_2, fruit maturity and the CO_2 regime.

One way to obtain the benefits of ULO CA but manage the risks is to use a dynamic controlled atmosphere system (DCA). Oxygen levels are varied according to the condition of the fruit, which is measured by specialist equipment. Oxygen levels are lowered to below 1 per cent which dramatically reduces respiration, and controls scald, maintains fruit firmness and prolongs storage life.

DCA systems let the fruit tell the cold store manager when it is at risk of entering anaerobic respiration. One method is to reflect light off fruit and measure the fluorescent intensity of the chlorophyll in the skin to indicate any low oxygen stress. Another DCA system measures ethanol being produced by fruit. Both these systems require very sensitive equipment. Based on the fruit condition the O_2 levels are held slightly above the anaerobic level. Because this anaerobic point changes during storage the O_2 levels are changed in response to the fruit – hence the term 'dynamic'.

DCA systems are not yet commercially operating in Australia but are a viable option in some countries. In these countries they are a viable alternative for growers wishing to store long-term fruit without the use of DPA or SmartFresh. The three main challenges are engineering based; having very well sealed rooms, having good atmosphere monitoring and generating equipment and having the specialist equipment to measure the condition of the stored fruit. No doubt there will be a period of learning as the DCA systems are to be adapted to our varieties and the condition our fruit is grown and picked in. Still it's definitely a technology Australians will see in the future.

Carbon dioxide. Traditionally CO_2 was allowed to be higher than O_2 during CA storage for most apple varieties e.g. 'Red Delicious', 'Gala', whilst for others CO_2 was kept lower than O_2 , e.g. 'Granny Smith' and 'Fuji'. Best practice for the majority of varieties is to ensure CO_2 is kept at a minimum 0.5 per cent lower than O_2. But for varieties that can tolerate increased CO_2 allowing levels to increase will further reduce respiration, which assists in prolonging an apples storage life.

Carbon dioxide has traditionally been removed by external scrubbers and by placing hydrated lime inside sealed rooms. When on-farm nitrogen generating equipment became affordable less, reliance was placed on scrubbers and lime as the flushing of rooms with nitrogen also removed some CO_2.

Ethylene. This odourless and colourless gas is active at very low concentrations. Because it is associated with ripening fruit we often think we can smell it because of the aromatics that ripe fruit give off in combination with ethylene.

Management of ethylene starts prior to harvest by picking fruit before ripening progresses too much. Many growers use ReTain to slow the ripening process for this reason. Growers do not deliberately harvest over-mature fruit but often it happens. The main reasons are they're waiting for more red skin colour development, waiting for the fruit to grow another size, or waiting to get enough good pickers through the front gate! ReTain inhibits ethylene production by fruit and is an excellent harvest management tool. Fruit sprayed with ReTain allows it to store better – it will stay firmer than untreated fruit going into storage.

Ethylene is interesting in that it is a by-product of respiration and its presence also promotes respiration, which in turn produces more ethylene. There is a feedback loop that speeds up as it progresses. Managing ethylene production has traditionally been by three methods; picking fruit before it had properly started the ripening process (often too green), keeping temperatures low and adjusting atmospheres (low O_2 and higher CO_2 than in a normal atmosphere). If O_2 levels are around 1.5 to 1.8 per cent then ethylene has a reduced stimulus effect on respiration, but at 1.8 to 2.5 per cent the effect is lost, so O_2 can really only be used as an ethylene management tool in ULO CA and DCA situations.

Ethylene accumulates inside the core of apples or pears and in the air spaces between cells. It then diffuses to the general atmosphere of the cold room. If the ethylene gas is removed from the room then a gaseous gradient will exist and ethylene will diffuse out of the fruits air spaces. Once outside the fruit it will have a reduced effect on promoting respiration. Hence the second part of traditional ethylene management was to remove it from the atmosphere within the cold store so that fruit wasn't exposed to increasing concentrations. This is done by regularly flushing the rooms atmosphere with nitrogen or by destroying the ethylene. This is achieved by burning it when the atmosphere was burnt with LPG to lower O_2 levels or burning it with electric elements if O_2 levels were optimum. Specialist ethylene scrubbers are also used which remove it by passing the atmosphere through chemical solutions that extract ethylene.

However, the modern way to manage ethylene is by using the SmartFresh (SF) technology. This works on a molecular level to block the fruits ethylene receptors and shut down ethylene production. SF is a very efficient way to manage ethylene because it stops its production in the first place. The sooner SF is applied to fruit after the harvest the greater the benefits. Commercial operators usually aim to fill a cold store in three-to-five days and treat as soon as possible after that. SF is a relatively new technology and cold store managers are still finding new benefits since it was introduced commercially to Australia eight years ago.

The basic benefits of increased firmness, less greasiness, greener background colour, superficial scald control and better shelf life after storage are well known by most growers and appreciated by the marketing chain and consumers. However, additional benefits are now being realised such as; the ability to delay the imposition of CA conditions, the removal of the need to CA store some fruit at all out to four-to-five months, less need to pack a room out quickly after cracking the CA seal, the reduction in shrivel and weight loss when fruit is stored at higher temperatures, the ability to manage fruit with water-core and the maintenance of Pink Lady quality when step wise cooling is used to manage internal browning. All these benefits are achievable with no loss of quality.

For a relatively small apple and pear producing nation Australia is very well served by several cool store technology companies. Management of atmospheres has become easier with the advent of reasonably priced automatic analysers and controllers but the skill (sometimes art) of knowing what levels of O_2 and CO_2 are required for each variety, fruit maturity and storage potential still requires human input.

Disorder management

There are a lot more storage disorders than diseases, so a successful post-harvest manager has to be a physiologist as well as an engineer. The four most common cold storage disorders are superficial scald, water core, bitter pit and internal browning. All have major influences that start in the orchard – so their management needs to start in the orchard.

Superficial scald is the most common of a group of scald disorders that also include senescent scald, sun scald, ribbon scald and chemical (DPA scald). It is oxidation of compounds in the fruits skin so it is more likely to occur in high oxygen atmospheres. Hence fruit stored in CA is less likely to scald and fruit stored in ULO CA and DCA is unlikely to scald. The two biggest predisposing factors are early harvest maturity and excessive heat experienced during the growing season.

Apart from the reduction of O_2 in atmospheres, the post-harvest management of superficial scald relies on two products to control it; DPA and SF. There are residue and disposal issues with DPA and its use is restricted in many countries, which can affect how export fruit is treated. DPA use on apples in Australia has reduced in recent years as SF has been adopted, however it is still the product of choice in pears. For SF to control scald in apples it has to be applied within seven days of harvest. Because fruit stored in ULO CA has a greatly reduced risk of scald, growers have the option of not using either product to control scald. However, the positive ethylene management benefits of SF are many and the only reason to choose neither DPA nor SF to control scald would be if fruit was destined for an organic market where these products were not acceptable. When DCA storage is developed further in Australia it will need to demonstrate the maintenance of fruit quality on our varieties and variable growing conditions. However, its ability to control superficial scald should be assured given that ULO CA storage has demonstrated this benefit in Australian situations.

Water core is a disorder, not a disease and only develops on the tree, but can reduce in storage or develop into a dark breakdown. Water core is caused when the air spaces between cells become flooded with a sorbitol (one type of fruit sugar) solution. The flooding looks water soaked and starts around the apple 'plumbing' of the vascular bundles. 'Red Delicious' and 'Fuji' are mainly affected but 'Sundowner' and 'Granny Smith' can also be affected.

Fruit affected by water core is sensitive to CO_2 damage. Its internal air spaces are full of liquid and CO_2 can't easily dissipate. This CO_2 damage is worse in CA storage as there are higher levels of CO_2 levels in CA than in regular atmosphere.

There are several different causes of water core. In really good growing seasons excess sorbitol moves from leaves to the fruit and builds up before it can all be absorbed into fruit cells and converted to other sugars and carbohydrates. Fruit of advanced maturity experiencing low night-time temperatures is prone. But water core can also be caused by extreme weather such as early freezing events (e.g. Washington State) or heat waves (e. g. Australia). The disorder is worse in fruit with low calcium levels, on trees with lighter crops or vigorous trees and on the fruit that gets exposed to the most heat and sunlight. The use of ReTain in the lead up to harvest can delay and reduce its development.

Fruit with mild water core can be managed by delaying its final cooling and keeping fruit in regular atmosphere. This will reduce its severity and it may disappear within two-to-three months of regular atmosphere storage. This works because the apple is still alive it can reabsorb sorbitol – and at warmer temperatures the re-absorption rate is higher. Conversely, CA storage slows down the apples metabolism and re-absorption of sorbitol is slowed. But if a mixture of delayed cooling, warmer storage and no CA is used this will allow ethylene driven ripening to happen, so it's important to use SmartFresh to stop this.

Bitter pit is caused by calcium deficiency and can be reduced with post-harvest calcium dips. However, there are several orchard factors that also play an important role in the development of this disorder; mainly tree nutrition, watering, climate, crop load and tree vigor. High levels of fruit calcium are also important in increasing fruit firmness, lowering respiration rates, reducing ethylene production and reducing fruit rots. There is nothing new in the treatment of bitter pit after harvest, although the susceptibility of fruit has reduced over the past 30 years.

The reasons for this are; the use of less vigorous rootstocks, adoption of longer pruning techniques, greater use of field calcium sprays, the reduced impacts of drought and heat waves by the moderating effects of irrigation and hail netting, the improved supply of calcium enabled by fertigation, the calming of vigorous varieties by the growth regulator Regalis, the widespread availability and use of pre-harvest calcium sprays and better crop loading.

In the past calcium was used to help control bitter pit by applying it to the soil as a fertiliser, to the fruit as a foliar spray and by immersing fruit in calcium dips. All three methods were considered important in some seasons and for some varieties. But with reducing fruit susceptibility some growers are not dipping in calcium and still successfully controlling bitter pit. Other growers are using reduced rates of calcium dips, especially on varieties that are susceptible to lenticel burn (e.g. Gala strains). One of the drawbacks of using SF is that it could make bitter pit damage worse - it doesn't cause the damage but makes it more noticeable.

Internal browning is mainly a disorder of 'Pink Lady' apples but can also occur in 'Sundowner' apples.

There are three types;

1. Cavity browning, a disorder caused by storage in high CO_2.
2. Diffuse browning, a type of chilling injury that starts in the orchard. It is the type of browning most commonly seen in colder growing districts and cooler seasons. It can be greatly reduced by elevated storage temps, up to 3ºC.
3. Radial browning which is a type of senescent breakdown and is seen in warmer growing districts. Again, in cooler years there is increased risk and late picked fruit is more at risk. Storing above 1ºC and keeping CO_2 below 1 per cent helps reduce risk.

Stepwise cooling and delaying the imposition of CA atmospheres reduces the risk of internal browning. There are no direct positive or negative effects of SF on internal browning however, the use of SF allows fruit to be step-wise cooled and stored at warmer temperatures with more confidence of maintaining firmness and greenness of the background colour.

There is a growing degree day model that has been developed to help growers understand the risk of internal browning in any given growing year. Starch should be used as an indicator of harvest maturity rather than fruit colour because second and third pick fruit is much more at risk. There is much to be gained from increasing fruit colour to allow earlier harvesting. There is not one best factor to improve fruit colour, but rather optimising plant genetics, potassium fertilising, watering, summer pruning, judicious use of Regalis and laying reflective materials under trees (e.g. Extenday, Sun-Up) if needed.