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Pome Fruit Maturation and Storage

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Summary

The harvesting of fruit at the correct maturity is essential to ensure maximum fruit quality after storage. Fruit that are tree ripe have maximum flavour and the shortest storage life so need to be allocated to immediate sale. Fruit that are harvested prior to the tree ripe stage have longer storage potential which is determined by the exact level of fruit maturity, fruit quality, pre storage treatments and storage conditions. For growers, a knowledge of fruit ripening processes and methods of monitoring them is essential to ensure the harvest of fruit suited to the particular target market. Methods of manipulating fruit maturity and the storage environment are useful tools to be used to ensure successful marketing of quality fruit.

This document outlines some of the important physical, hormonal and biochemical processes of pome fruit maturation. It describes some simple methods of monitoring the rate of maturation and predicting when fruit will be ready to harvest. The data required for accurate assessment of harvest maturity, and hence, potential storage life is outlined. If correctly collected this data can assist in protection against poor out turns, litigation and insurance claim disputes. In addition to measurement of fruit maturity, methods of modifying the rate of maturation are discussed. Finally, the impact of storage technologies on storage and shelf life of the fruit are described.

Apple development

The fruit growth curve for apples is shown in figure 1. Soon after flowering apples enter phase I of fruit development where growth is due to cell division resulting in a rapid increase in the number of cells in the fruit. In apples, cell division occurs for approximately 50 days during which time the majority of the fruit cells are produced. In some fruit crops, such as peaches, the fruit then enter phase II of fruit development where there is minimal increase in fruit size. Apple and pear fruit development, however, does not appear to enter phase II but instead the transition between Phase I and III is continuous. In stage III the fruit continue to grow, however, this growth is due to the enlargement of the cells rather than cell multiplication.

The impact of tree stresses on the quality and storage potential of apples and pears will depend on the growth stage of the fruit when the stress is experienced. A stress at flowering will result in poor fruit set and a low crop load, a stress during cell division will result in lower cell numbers that are larger at harvest and these fruit will have potentially poor storage characteristics, and a stress during cell expansion causes smaller fruit, although they should have good storage characteristics. In this context, a stress can be seen as any attribute that reduces the rate of physiological activity in the tree such as cold weather, water logged soils, low light, drought, lack of nutrients etc. Hence conditions during the growing season will have an impact on the harvested fruit storage potential and every season will produce fruit with different storage characteristics.

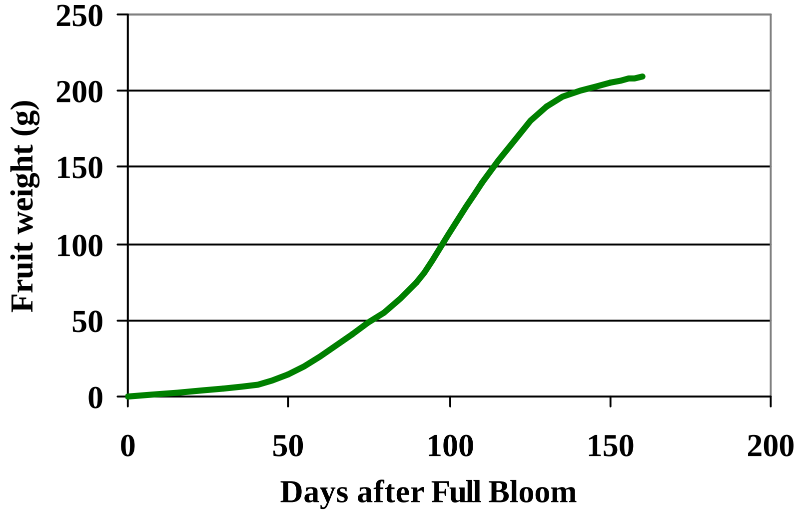

Figure 1. The fruit growth curve for apples.

There is a laboratory procedure to determine the alcohol insoluble solids content of the fruit which is a measure of the quantity of cell wall material in the fruit. This provides a good measurement of the storage potential as it provides an indication of the cellular strength of the fruit. Unfortunately a firmness reading, using a penetrometers, also measures the turgor or water pressure in the fruit so it does not provide a good indicator of the storage potential of the fruit. An analogy can be drawn with two balloons, a thin walled one and a thick walled one. They can be blown up to the same pressure or penetrometer reading, but after storage (say a week or two) the thin walled one will have lost a lot of air and will be flabby, while the thick walled one will still be firm. Hence, at the packing shed, a measure of the potential storage characteristic of the fruit is to measure the fruit firmness at harvest and after 10 days at room temperature. Fruit with a poor storage potential will soften rapidly in this period (say by more than 0.7kg depending on region). Ideally this procedure should be carried out in identical conditions (say 20°C and 60% RH) from one season to the next so a true comparison can be made. For example, Tasmanian Gala apples in 2007 were harvested at 8.0 kg and after 10 days at 20°C they were at 7.4 kg giving a 0.6 kg change. In 2008 they were harvested at 8.1kg and after 10 days at 20°C they were at 7.3 kg giving a 0.8 kg change, indicating that they will not store as well in 2008.

Hormones associated with ripening

The most commonly recognised hormone of pome fruit ripening is ethylene. Ethylene is a gas and is produced by fruit as they approach maturity. A concentration of less than 1ppm in the atmosphere is sufficient to stimulate a rapid rise in the rate of fruit ripening including the rate of starch conversion, fruit softening and colour development. A feature of this hormone is that the fruit is stimulated to produce more ethylene leading to a rapid build up of ethylene in the atmosphere causing other fruit to ripen. As ethylene is also produced from exhausts from diesel, petrol and gas engines it is not uncommon for fruit storage rooms to reach levels greater than 100ppm during loading and this stimulates the fruit to increase its rate of ripening prior to correct storage methods being applied. This is also the reason for maintaining the catalyst on CA equipment, as an inoperative unit will result in large volumes of ethylene being pumped into the CA room during the initial pull down phase of storage.

Another hormone commonly associated with fruit ripening is abscisic acid (ABA). While its role in pome fruit ripening is poorly studied it has been shown to increase in ripening fruit (from 140 nmole/kg at the start of harvest to over 270 nmole/kg at the end of harvest) and the application of ABA to the trees stimulates fruit colouration demonstrating its bioactivity (figure 3). ABA is commonly produced by roots in water stressed situations to prevent rapid shoot growth and to stimulate the production of dormant buds. This hormone is also present in the tree buds in late winter and its decline allows the shoot to grow in spring.

Finally another common plant hormone with potential to affect fruit maturity is gibberellic acid (GA). This material is now routinely used by the cherry industry to increase fruit size, firmness and delay harvest. In effect, this hormone is the counterbalance to ABA and ethylene and its presence in the tree restricts ABA and ethylene production. Unfortunately no reports for the use of this material on apples for this purpose have been located.

Measurement of fruit ripening

In the laboratory it is possible to measure the hormones of fruit ripening in order to monitor the rate of fruit maturation. Unfortunately the equipment and methods are expensive and not practical at most orchards. Hence, in the orchard the effect of these hormones on the fruit is monitored to observe the rate of fruit ripening. Commonly we measure the level of starch, firmness and sugars (TSS,) and sometimes seed colour. The methods used are simple and all orchardists should be competent in their measurement.

Unfortunately, in the process of investigating insurance and legal claims, almost no grower measures fruit maturity correctly. Here are some key areas that commonly need attention;

1) Having made a measurement record the results in a book. Memory does not stand up well especially if dealing with insurance companies or in court. The number of cases I have been involved in where there are no records is staggering. Records are your proof that the fruit was sound at harvest and after storage, and that the claims being made in the marketplace are incorrect or not sound.

2) Make good measurements. For starch and fruit firmness a minimum of 20 fruit are needed. This is to ensure an accurate figure as shown in figure 2. Measurement of a smaller number of fruit will give false results. The measurement and recording of one fruit is worthless. Practically a common practice at supermarket distribution centres is to measure 10 fruit and if the reading is marginal then a further 10 fruit are measured to ensure an accurate reading. It is better to measure 20 fruit from across a block every week than 1 fruit per day from each picking. I have growers who complain about the fact that this would use 100 fruit per day instead of 10 and this is a waste of fruit. Given that growers often harvest 100 bins per day, approximately 200,000 fruit, then 100 fruit is a minor consideration.

3) Ensure that the data collected is used. I was involved in one insurance claim where good measurements were made and data was recorded in a book. At the time of marketing, the fruit had internal browning and this was put down to a slightly high CO_2 level during storage. An insurance claim was made, however, upon inspection of the maturity data the fruit was clearly over mature at harvest and should not have been placed in long term storage. In this case the person who made the maturity measurement, the orchard manager, did not advise the partner in the shed that the fruit was already ripe and should be sold quickly. He was too focussed on getting the fruit off the trees.

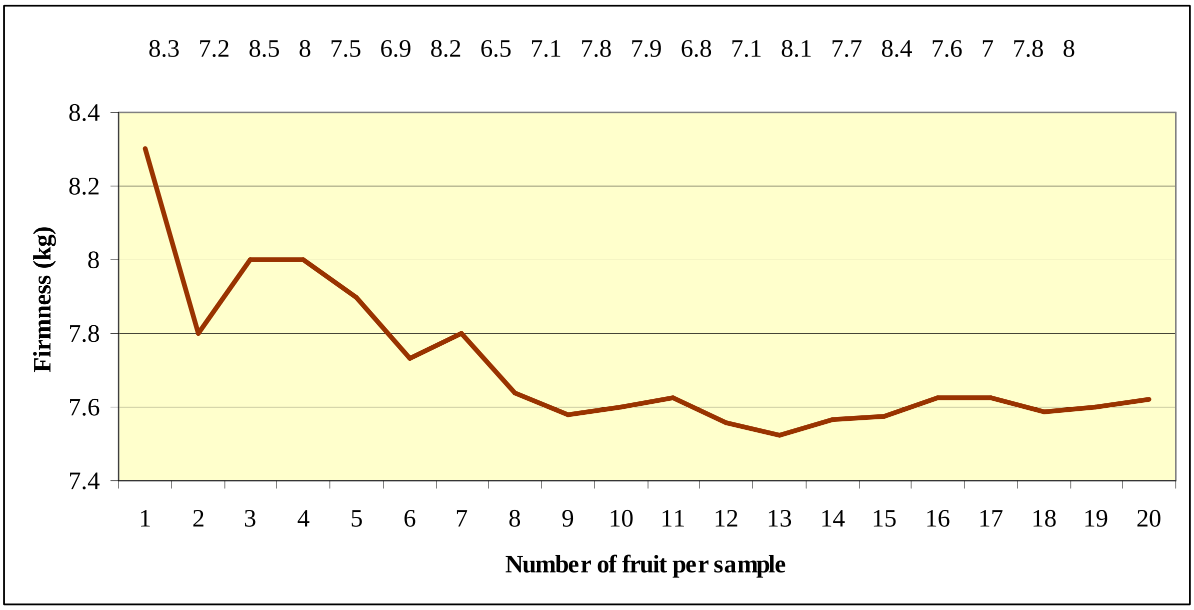

Figure 2. A typical set of fruit firmness data showing the number of fruit in the sample and the effect on the mean level of fruit firmness.

Problems with under mature fruit

There is no need to dwell on this. Under ripe fruit has poor flavour, size, colour, and often suffers from shrivel in storage. This leads to poor quality, low prices and possibly market rejection. **This costs the grower dollars ($$$$)**

Problems with over mature fruit

Again no need to dwell on this. Overripe fruit that is stored suffers from soft problems, often of poor texture, fruit rots, poor storage characteristics, senescent breakdown and possibly market rejection. **This costs the grower dollars ($$$$)**

It is important to know the maturity of the fruit at harvest and to have a system to correctly store and market the fruit while they are still sound.

Modifying the rate of fruit maturation

If a lot of fruit of a particular variety is grown and needs to be harvested then it might be wise to control the rate of fruit ripening to spread out the labour requirements. This may be initially be performed by choosing a range of different orchard blocks. Most growers are aware that particular blocks produce fruit that are harvested early while others are late. Alternatively Ethephon can be applied to advance maturity and on Tasmanian Pink Lady apples this did not affect their storage potential. In addition to Ethephon, applied ABA has been shown to advance fruit maturity although currently there is no commercial product. Of interest is that the roots of trees produce ABA if stressed such that conditions such as root disease, dryness, waterlogging, root pruning etc will advance fruit maturity and harvest date.

Acting in reverse the Retain® is a product that reduces the production of ethylene in the apple and in warmer regions, where apples produce ethylene prior to harvest, this material has proved extremely effective at delaying harvest date. In the future it may be that we discover that the application of GA prior to harvest also has this effect although this should not be practiced until its effects are known and documented.

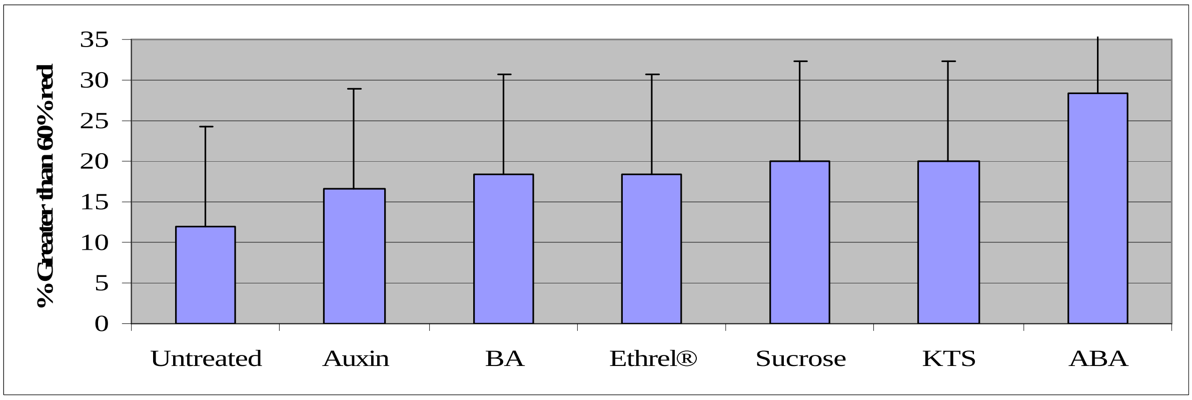

Figure 3. The impact of an auxin, cytokinin (BA), Ethrel®, sugar, potassium (KTS) and ABA sprays on colour development of Fuji apples (% marketable) in Tasmania. Bars = 5% LSD values.

In Australia there is an increasing use of reflective cloth to improve fruit colour. Due to this colour improvement growers often believe that this treatment advances fruit maturity. While this may be the case in warmer climates, in Tasmania the opposite has been found (figure 4). The use of reflective cloth, while advancing fruit colour, delays fruit maturity. Of interest is that this material, in Tasmania, if applied during the first 50 days after flowering, results in larger fruit at harvest due to improved growing conditions during cell division.

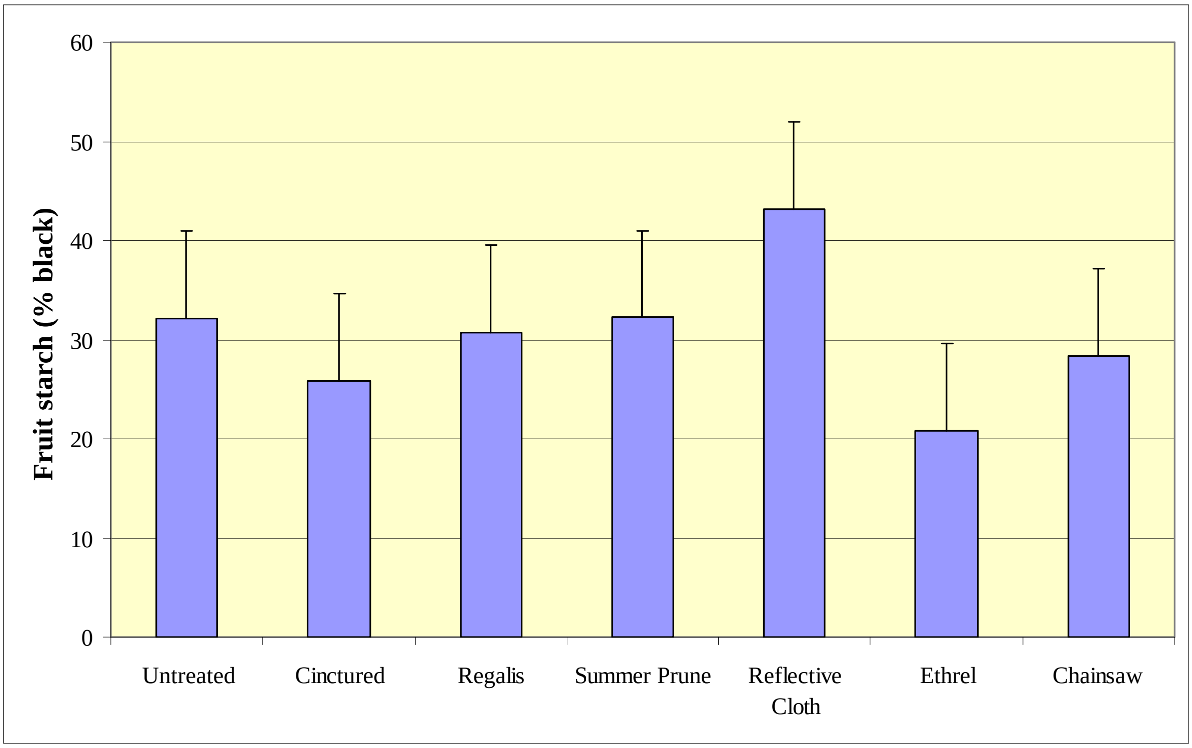

Figure 4. The effects of various colouration treatments on fruit starch content of Pink Lady® apples in Tasmania. Bars = 5% LSD values.

Prediction of fruit maturity / harvest

In the late 1990's the author investigated methods of predicting the date of harvest. At the time there were four commonly used systems, the number of days from flowering, the climatic model, the date of T (when the stalk is at right angles to the fruit at the point of attachment) and the Strief index.

After several years of studying this in the field it was found that in Tasmania (and other regions of Australia), flowering is over an extended period and the exact date of full bloom is difficult to standardise and monitor. In apple regions where there are extreme climate differences between summer and winter the date of full bloom can be accurately determined. This combined with variable climate after flowering led to a highly variable number of days from full bloom till harvest so this system was found to be poor in our environment.

The date of T provided a reasonable constant date that could be accurately measured and surprisingly, most cultivars go through this stage in the same week. Physiologically this occurs at about the same time as the termination of cell division, just after fruit start to expand laterally so it has some physiological meaning as well. When this date is combined with subsequent temperature information a good estimation of harvest date can be made.

The Strief index was found to be clumsy, due to the fact that it generated a curve specific to each cultivar and the nature of the equation was that when there was a lot of starch the estimate was poor but improved as starch dissipated and fruit became over mature. As a result the equation was modified to generate a straight line and improve its accuracy under high starch levels. This modified equation provided an excellent estimate of harvest date from about 30 days before harvest and was supplied to several growers in Tasmania who looked forward to the information (figure 5). Unfortunately the system failed to be commercial and was terminated in 2004.

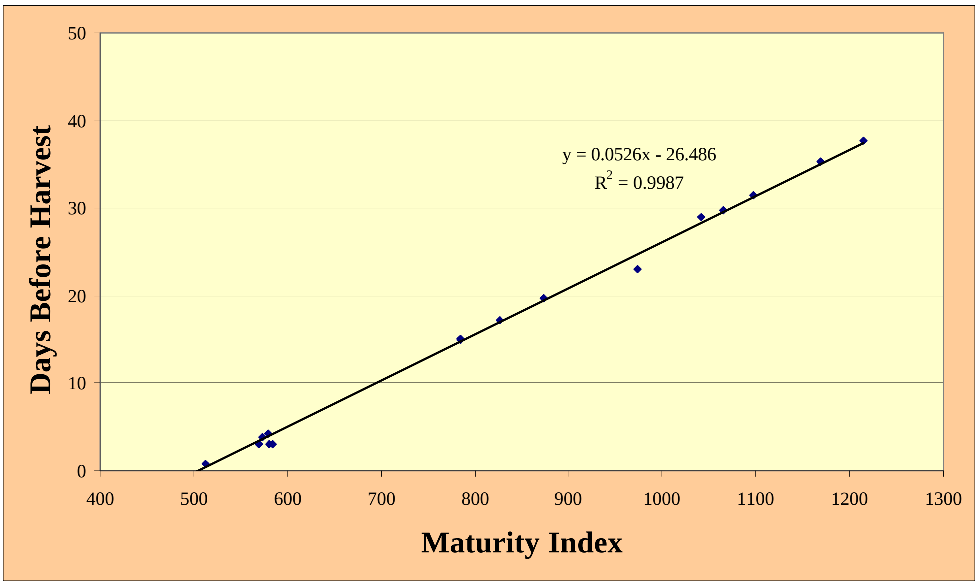

Figure 5 Maturity Index prediction of days till harvest for Pink Lady® apples. Data from three seasons and verified in the fourth season.

Storage

Once harvested apples are in a state of decline, using their stored carbohydrates (sugars and starch) as an energy source to stay alive. To maximise storage life and fruit value it is imperative that fruit are harvested as close to ripe as possible but with enough food reserves to survive the storage period till marketing and consumption. Tree ripe fruit, while having the best flavour and eating quality have low food reserves and have started their decline (stage IV of fruit development) . These fruit are best marketed immediately. With earlier harvests there are sufficient food reserves to maintain fruit quality in storage.

An objective of storage is to slow down physiological processes in order to maintain the apple food reserves and fruit quality for as long as possible. The quicker this is done then the longer the potential storage duration. In practice there are four main ways we slow down fruit physiology and stabilise it just before problems start to appear.

1) Temperature. In practice, ripening physiological processes are just controlled chemical reactions. A feature of chemical reactions is that they occur more slowly in colder temperatures. This is why car batteries often fail at the start of winter, they are colder. Unfortunately not all reactions are slowed to the same degree so if the temperature is reduced too far then there develops an imbalance of chemicals in the cells that can cause damage, termed chilling injury or low temperature breakdown. This usually expresses itself as a moist brown discolouration in the centre of the flesh of the fruit. Initially it tends not to affect the core region or the area just under the skin. This has been identified as a cause of internal browning in Pink Lady® apples in Tasmania and in this variety this symptom is now called diffuse internal browning. Often this problem can be overcome with a practice called stepwise cooling where fruit temperatures are dropped to say 5°C for 2 weeks prior to further temperature reductions.

2) Oxygen. The method living organisms use to obtain energy from food is called respiration. This is where cells (animal and plant) combine sugars with oxygen to produce energy, carbon dioxide, water and heat. It is possible to reduce the level of oxygen in the atmosphere to a level where the fruit cells are forced to reduce their rate of respiration. This reduces their rate of starch and sugar consumption extending the potential storage life of the crop. Apples held at 5°C in an atmosphere containing only 2.5% oxygen will have half the rate of respiration. As for temperature, some energy to maintain life is needed by the fruit and if the oxygen levels are reduced too low in order to obtain energy anaerobic respiration or fermentation commences. This produces alcohol as an end product and this can damage the fruit. Symptoms include a fermented smell, off aroma and large areas of the skin and flesh may turn a pinkish brown.

3) Carbon dioxide. This gas is one of the by products of respiration such that a build up in the atmosphere will also slow down the rate of respiration. This gas also appears to have other effects such as reducing the fruits sensitivity to the ripening hormone ethylene. Unfortunately apples, unlike many other fruit, are sensitive to elevated levels of carbon dioxide and damage can occur at levels above 3%.

4) 1-MCP. This material is marketed as Smartfresh®. It works by deactivating the ethylene sensitive gene in the cell such that the fruit cannot sense the presence of ethylene in the atmosphere. As such the fruit is not stimulated by the ripening hormone to start or continue ripening. This results in fruit with a low rate of respiration and long storage life. Unlike carbon dioxide, however, this material maintains the fruit in this condition after it is removed from the controlled atmosphere store such that fruit continue to remain firm after a period of marketing (Figure 6).

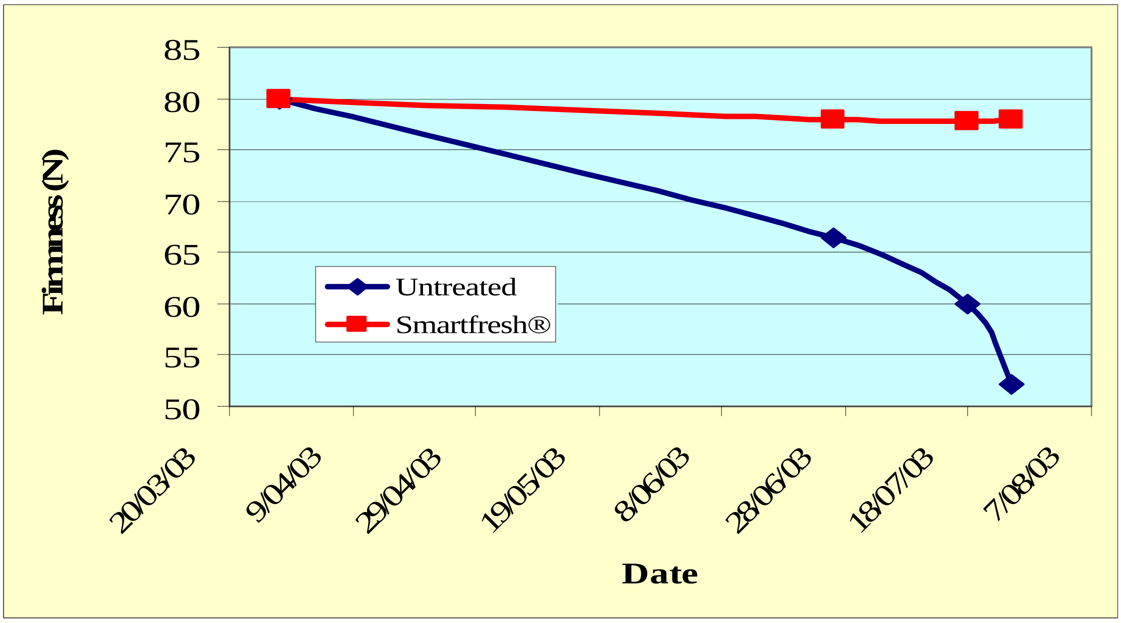

Figure 6. Storage duration and Smartfresh® effects on Jonagold fruit firmness during controlled atmosphere storage, transport to market and for the duration on the supermarket shelf.

Storage life and shelf life

Fruit have a finite time that they can be stored. While we can easily manipulate this time with harvest maturity, rate of cooling, Smartfresh and storage atmosphere the duration is still limited. The longer a piece of fruit is in storage, the shorter its shelf life and the shorter the time from purchase to consumption. If fruit is over stored then it can be removed from controlled atmosphere storage in excellent condition but it has insufficient reserves to maintain life and enzymes of degradation will act quickly. Hence fruit will soften, lose flavour and become mealy extremely quickly, possibly by the time that the fruit reaches the market causing unhappy consumers. If this occurs then the product will be rejected puzzling the grower because 'it was fine when it left here'. Better store houses have a practice of regularly removing fruit and placing it in a controlled ripening room to ensure that there are no unexpected market failures due to over storing of fruit. If a line of fruit are marginal then one possibility that works well is the employment of modified atmosphere box liners. This effectively extends the storage time in a high carbon dioxide and low oxygen environment and can make the difference between marketing failure and marketing success.