Tracking Pink Lady apple firmness

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Agriculture Victoria

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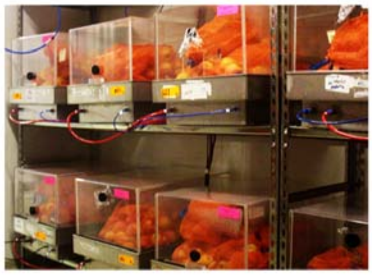

TRACKING PINK LADY APPLE FIRMNESS

Horticulture Australia Project
Number AP 01036 (November, 2004)

Final Report

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Horticulture Australia Project Number AP01036
Tracking Pink Lady apple firmness
Final Report
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Purpose:

1. Determine the effects of fruit nutrient status, harvest maturity, crop load on Pink Lady apple firmness after storage and shipping.
2. Determine the effects of rootstocks and retardation on Pink Lady apple firmness.
3. Determine the effect of SmartFresh™ on Pink Lady and Jonagold apples firmness.

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November 2004

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1. MEDIA SUMMARY

As a result of this project, growers and packers have a new fruit firmness management tool in SmartFresh™ to avoid soft Pink Lady apple outturns on domestic and export markets. Furthermore the project has investigated a number of other production and handling practices that may impact on fruit firmness.

Ethylene the fruits' natural ripening hormone, has been identified as a prime factor in soft fruit outturns. SmartFresh™ is a gas that inhibits ethylene action when applied shortly after harvest to warm or cooled fruit. Fruit treated with SmartFresh™ were significantly firmer than non-treated fruit after medium and long term air and CA storage plus a simulated marketing period. In 2002 and 2003 actual trial shipments of SmartFresh™ treated fruit from 12 orchards in the Goulburn Valley were sent to the UK. In both years the SmartFresh™ treated fruit from all orchards exceeded the market specifications whereas the untreated fruit from most orchards did not meet the export standard. SmartFresh™ insures against soft fruit outturns provided the fruit leave Australia with an average firmness of 7.5 kgf and less than 10% of the fruit are 7.0 to 7.4 kgf. Supplementary work to this project conducted by Dr Gordon Brown in Tasmania showed that treatment of Jonagold and Gala apples with SmartFresh™ resulted in fruit that were well above market specifications.

Overall, the fruit from the optimum harvest time was significantly firmer than the fruit from a later harvest after long-term storage. It did not seem to be linked to starch levels. It was more the fact that earlier picked fruit were firmer and remained that way during storage compared to later picked fruit.

The firmness of the fruit should be monitored both before and during the harvest period. If the fruit is harvested with a firmness greater than 8 kgf with less than 10% of a sample population less than 8 kgf then with good post harvest management it should outturn well after long term storage and would be suitable for export. However, in a severe drought year such as the 2003 season, caution should be taken in predicting outturn firmness based on harvest firmness.

Apples should be held at close to 0^{o}C to minimise quality loss through increased fruit respiration. In the simulated shipping trials conducted as part of the static trials and the SmartFresh™ trials the effects of 6 weeks simulated shipping at 4^{o}C on fruit firmness was variable. In some trials there was a significant reduction in fruit firmness at 4^{o}C compared to maintaining the cool chain at 0^{o}C. The response of the fruit to poor storage temperature differed between orchards. Given that shipping containers will most likely have warmer spots during transport it is possible that shipping temperature is a limiting factor to achieving firm outturns in the UK for fruit from some orchards.

There are many publications that show the benefits of elevated calcium with appropriate nitrogen to calcium ratios on improved fruit firmness. However, the industry wanted to know if foliar sprays applied during the early fruitlet stages 25 grams to 55 grams, could correct mineral imbalances in time to achieve a normal level at harvest. In the two drought years that the higher nutrient input were trialed, there was no evidence that the early warning system wasn't working. The nutrient levels did improve between the 25 gram and 55 gram fruitlet stages as a result of the higher nutrient input applied between the 25 gram and 50 gram fruitlet stages. However, there were also orchards on lower nutrient inputs whose fruit had similar nutrient levels 90 days after full bloom (DAFB) and at harvest. Therefore, the results from this project are inconclusive. The drought conditions were probably having a bigger effect on fruit firmness than the nutrient levels in the fruit. The nutritional status of the fruit needs to be viewed in relation to the crop load and tree vigour. It may be possible to carry two consecutive high yielding years provided the trees vigour is reduced and the nitrogen to calcium ratio is low meaning that the calcium available for the fruit development is not a limiting factor for firm fruit. Nutritional trials are usually run over many years because the benefits of proper nutrition can take time. Two years was not long enough, particularly during drought years to fully determine the benefits of early fruitlet analysis on fruit firmness at harvest and after storage and export.

Flesh browning (FB) also known as 'internal browning' of Pink Lady apples is an undefined physiological condition of fruit, which is expressed during storage under certain conditions. FB was first observed in the 2000 season. The incidence and severity increased over the next two seasons being worst in 2002 season. FB was not a problem in 2003. Three types of browning were characterised in this project, Type I senescent (diffuse browning in the cortex), Type II radial (rays of browning in the cortex), Type III carbon dioxide (patches of browning and associated cavities in the cortex). The problem appears to be orchard specific, with large or misshapen, late maturing fruit being more susceptible. Seasonal variations, root disease and growth retardation methods influence the risk of getting FB. In this study, SmartFresh™ applied to Pink Lady apples harvested at commercial maturity had no significant effect on the incidence and severity of internal browning.

Fact sheets have been prepared for minimising firmness loss of Pink Lady apples for domestic and export markets.

2. TECHNICAL SUMMARY

Firmness is a key characteristic that influences consumer acceptability of apples. Firmness is influenced by pre-harvest and post-harvest factors. Pink Lady apple premature softening in storage was identified by the industry in 1998 as a significant problem. This was reflected in 1998 and 1999 when some export shipments of Pink Lady apples were rejected or down graded because the fruit was too soft, that is, greater than 10% of the fruit were less than 6.5 kgf. The purpose of this research project was to identify when and why Pink Lady apples soften. The probable causes for loss of firmness are well documented. It was proposed to determine which of the known factors such as fruit nutrient status, harvest maturity, crop load, tree vigour, retardation treatments, colouration, root-stocks, storage atmosphere, ethylene and the use of SmartFresh^{TM}, an ethylene inhibitor and shipping temperature were the major factors contributing to soft fruit on arrival in the UK.

Ethylene is the fruits natural ripening hormone. SmartFresh^{TM} (active ingredient, 1-methylcyclopropene) is a gas that blocks the action of ethylene and the effect on firmness loss during storage, shipping and marketing is significantly reduced. A single application of SmartFresh^{TM} at 625 parts per billion (ppb) applied shortly after harvest to warm or cooled fruit significantly improved fruit quality (firmness, colour and total soluble solids). While SmartFresh^{TM} is not a replacement for refrigeration, apple quality will deteriorate slower under sub-optimal temperature conditions during shipping if previously treated with SmartFresh^{TM}. In 2002 and 2003 actual trial shipments of SmartFresh^{TM} treated Pink Lady apples from 12 orchards in the Goulburn Valley were shipped to the UK. SmartFresh^{TM} treated fruit from all 12 orchards met import market specification for firmness in both years whereas fruit not treated with SmartFresh^{TM} from most orchards failed to meet the required standard. Supplementary work to this project conducted by Dr Gordon Brown showed that treatment of Jonagold and Gala apples with SmartFresh^{TM} resulted in fruit that were well above the market specifications. Production of ripe aromas is stimulated by ethylene during apple fruit ripening. Aromas and flavours were not measured in this project. The impact of SmartFresh^{TM} on ripe aromas and flavours from overseas results suggest that consumer like SmartFresh^{TM} treated fruit. However, the acceptance of SmartFresh^{TM} treated fruit by Australian consumers will need to be established.

Overall, the fruit from the first harvest was significantly firmer than the fruit from second harvest after long-term storage. It did not seem to be directly correlated to starch levels. It was more the fact that earlier picked fruit were firmer and remained that way during storage compared to later picked fruit.

The firmness of the fruit should be monitored before and during the harvest period. If the fruit is harvested with a firmness greater than 8 kgf but with less than 10% of a sample population less than 8 kgf then with good post harvest management it should outturn well after long term storage and would be suitable for export. However, in a severe drought year such as the 2003 season caution should be taken in predicting outturn firmness based on harvest firmness

Ethylene is a major limiting factor for firm fruit outturns. This was demonstrated by the use of SmartFresh^{TM} to block ethylene action that significantly increased fruit firmness for all orchards. Therefore, if possible, the rooms need to be scrubbed for ethylene while the rooms are being filled and during storage, if less than 1 ppm in the storage room atmosphere can be achieved. In addition, the fruit needs to be cooled rapidly after harvest and the fruit stored in 1.5% oxygen. The alternative to ethylene scrubbing is treating the fruit with SmartFresh^{TM}.

Apples should be held at close to 0^{o}C to minimise quality loss through increased fruit respiration. In the simulated shipping trials conducted as part of the static trials and the SmartFresh^{TM} trials the effects of 6 weeks simulated shipping at 4^{o}C on fruit firmness was variable. In some trials there was a significant reduction in fruit firmness at 4^{o}C compared to maintaining the cool chain at 0^{o}C. The response of the fruit to poor storage temperature differed between orchards. Given that it is likely that shipping containers will have warm spots during transport it is possible that poor shipping temperatures are a contributor to soft outturns in the UK for fruit from some orchards.

There are many publications that show the benefits of elevated calcium with appropriate nitrogen to calcium ratios on improved fruit firmness. However, the industry wanted to know if foliar sprays applied during the early fruitlet stages 25 grams to 55 grams, could correct mineral imbalances in time to achieve normal level at harvest. In the two drought years that the higher nutrient input was trialed, there was no evidence that the early warning system wasn’t working. The nutrient levels did improve between the 25 gram and 55 gran fruitlet stages as a result of the higher input applied between the 25 gram and 50 gram fruitlet stages. However, there were also orchards on lower nutrient inputs whose fruit had similar nutrient levels 90 DAFB and at harvest. Therefore, the results from this project are inconclusive. The drought conditions were probably having a bigger effect on fruit firmness than the nutrient levels in the fruit.

The nutritional status of the fruit needs to be viewed in relation to the crop load and tree vigour. It may be possible to carry two consecutive high yielding years provided the trees vigour is reduced and the nitrogen to calcium ratio is low meaning that the calcium available for the fruit development is not a limiting factor for firm fruit.

The drought conditions were probably having a bigger effect on fruit firmness than the nutrient levels in the fruit. Nutritional studies are usually run over many years and nutritional programs such as Phosyn full nutritional program can take several years before the full benefits are achieved. Therefore, more years of evaluation are needed to clarify the benefits of the early warning nutrient correction system. Hopefully, this will not include more years of drought conditions.

Over all, there appears to be a need to get more sprays on during the 50 DAFB when the cell division phase of fruit growth occurs to maximise the mineral levels in the fruit. This should have maximum effect on improving Pink Lady apple firmness, colour and return bloom of the trees in subsequent seasons.

DPI, Knoxfield will continue to work with Phosyn in analysing the full set of mineral data and the results will be made available to the industry when they are complete.

A postharvest calcium dip of apples has been shown to improve fruit firmness outturn for other apple varieties. In this project, there was no significant effect of "Stopit" calcium dip (16% calcium as calcium chloride) used at the rate of 1.35 litres per 100 litre of water on fruit firmness after 8 months CA storage. This has also been confirmed by Gordon Brown in the HAL funded project on 'Jonagold' apples (AP99031). The failure to achieve a significant result may have been due to 1) the recommended rate being too low to benefit fruit firmness, or 2) the fruit was not dipped on the day it was picked. Further research is needed to confirm these hypotheses.

The weather as measured by accumulated degree-days was not significantly different between the orchards and was not seen as a major factor affecting fruit firmness. However, the micro-climatic differences associated with orchards 1, 4, 9 and 10 that were close to the Goulburn river cannot be overlooked. Early red colour development and harvesting fruit less mature would have a positive effect on firmness.

Flesh browning (FB) of Pink Lady apples is a physiological condition of fruit, which is expressed during storage. FB was first observed in the 2000 season. The incidence and severity increased over the next two seasons being worst in 2002 season. FB was not a major problem in 2003. Three types of browning were characterised in this project. Type I: senescent (diffuse browning in the cortex), Type II: radial (rays of browning in the cortex), Type III: carbon dioxide (patches of browning and associated cavities in the cortex). In 2001 and 2002, fruit from 6 and 12 orchards respectively harvested at commercial maturity were stored in the same controlled atmosphere CA (2.5% O_2 plus 1% CO_2) tent for 4 months before being shipped to the UK. FB assessments showed that only some of the orchards had FB that suggests the problem is orchard specific and that the fruit is pre-conditioned to the disorder prior to storage. Seasonal conditions strongly influence the incidence of FB and it was absent in 2003. Dr Gordon Brown’s work shows that over mature fruit at harvest, root disease, less vigorous root-stocks and cincturing are factors that increase the risk of getting FB. Regalis® a growth inhibitor and reflective cloths are treatments growers could use to reduce the risk of fruit developing FB. Storage quality (firmness and total soluble solids) was not affected by rootstock, cultural practices (cincturing, chain-sawing, summer-pruning, Regalis®, Retain® / Ethrel®, or reflective cloth). Work done with the ethylene inhibitor SmartFresh™ at DPI-Knoxfield suggests that ethylene is not influencing the incidence and severity of FB.

Fact sheets have been prepared for minimising firmness loss of Pink Lady apples for domestic and export markets.

3. INTRODUCTION

Firmness is a key characteristic that influences consumer acceptability of apples. Firmness is influenced by pre-harvest and post-harvest factors. Pre-harvest factors that influence apple firmness at harvest have been reviewed by DeEll et.al. 2001; Harker et. al. 1997; Johnston et al. 2000c and Sams, 1999. However, there is limited information available on the influence of pre-harvest factors on softening rates of apples through storage (Johnston et al. 2000c). Pre-harvest factors include climatic effects, temperature, light intensity, sunshine hours, rainfall, cultural practices such as mineral nutrition, timing, irrigation, thinning, tree management, growth regulators and genetic factors such as rootstocks and interstocks. Johnston et. al., (2002c) reviewed the pattern of softening for harvested apple fruit and how it is influenced by different pre-harvest at harvest and post-harvest factors. Many apple cultivars have three phase changes in firmness loss. Fruit soften slowly during phase (I), more rapidly during phase (II) which once induced is difficult to stop and phase (III) softening is slow. It is important to prolong phase (I) if firmness is to be maintained during long-term storage. However, despite many softening studies, there is still poor understanding of what causes firmness variation in the marketplace. The major objective of post-harvest procedures is to maintain fruit firmness during storage, grading and transport to have crisp fruit reach the consumer. This is achieved by correct harvest maturity and limiting respiration and ethylene production during storage and transport.

Premature softening of Pink Lady apple in storage was identified by the industry in 1998 as a significant problem. This was reflected in 1998 and 1999 when some shipments of Pink Lady apples to the UK were rejected or down graded because the fruit was too soft. The Australian apple industry is domestic market driven. The domestic market demand highly coloured fruit which can result in the fruit being softer at harvest than is optimum for fruit destined for long-term storage and export. Overseas market quality standards for fruit firmness are much higher than the standards required on the domestic market. The UK standard requires Pink Lady apples to have a firmness value greater than or equal to 7 kgf with a minimum acceptance of 10% at 6.0 to 6.9 kgf compared to 6.5 kgf for domestic consumption. But the rewards can be higher for exported fruit. UK consumers are prepared to pay a premium for Australian Pink Lady apples. Therefore, if Australian growers are to maintain a premium status for their fruit, poor outturns must be stopped. Otherwise Australia's reputation as suppliers of high quality apples will be damaged and will result in reduced financial returns.

Growers seeking a greater return for their Pink Lady apples will need to export and this will require planning to start immediately after harvest, targeting specific blocks. In 2003 there was an over supply of Pink Lady apples on the domestic market. The pressure to export will be greater in years to come and provided the exchange rate is favourable, growers can make better money from exporting their fruit compared to returns on the domestic market. However, if the Australian Pink Lady apple market share is to increase in the UK, it will require consistent quality apples.

The purpose of this research project was to identify when and why Pink Lady apples soften. The probable causes for loss of firmness are well documented. It was proposed to determine which of the known factors such as fruit nutrient status, maturity, crop load, tree vigour, retardation treatments, colouration, root-stocks, storage atmosphere, ethylene and the effect of SmartFresh™, an ethylene inhibitor and shipping temperature are major limiting factors contributing to soft fruit on arrival in the UK.

4. GENERAL MATERIALS & METHODS

4.1 Project methodology and experimental design

Fruit was harvested from 6 orchards (2001 harvest) and 12 orchards (2002 and 2003 harvests) in the Goulburn Valley. The trees were grown on MM106 rootstock and the tree age ranged from 6 to 9 years (in 2002). The names of growers participating in this project remain confidential. Therefore, each orchard was given an identifying number. The same orchard numbers were used through out the report, for every experiment conducted at DPI, Knoxfield. At each orchard, five field blocks of trees were tagged and the fruit from each field block was matched with its storage replicate block design.

4.2 Fruit Quality Measurements

4.2.1 Firmness

Fruit was assessed for firmness on both sides of the fruit (chosen at random) using a hand-held Effigi penetrometer or in the UK a automated Food Texture Analyser (FTA). A strip of skin was removed with a vegetable peeler from the cheek of the fruit, midway between the stem and calyx, and the plunger inserted up to the scribed line. The plunger diameter was 11 mm. Results were recorded in kg force and the mean of several apples was calculated.

4.2.2 Maturity

Fruit maturity was assessed using the starch iodine test, which measures the distribution of starch in the fruit, and the extent to which starch has been converted to sugars. At each harvest twenty fruit were picked at shoulder height from a representative sample of trees. Apples were assessed as soon as possible after picking using the Ctifl 10 point scale starch index scale, where 1 = no starch conversion in the apple interior and 10 = no starch left in the apple interior. Patterns were compared using a radial type rating scale (see Section 6.2.6. Plate 1).

4.2.3 Total Soluble Solids

Total soluble solids (TSS) was measured using a KRÜSS model DR 10/32 digital refractometer or a hand held visual refractometer. Individual fruit were measured, using the juice expressed while conducting firmness tests and the mean value was then calculated.

4.2.4 Colour

Fruit skin colour was measured with a Minolta CR-200 Chromameter (Minolta, Osaka, Japan) using the white calibration tile and a C illuminant (6774 k). Hue angle (H°) was calculated from the L, a and b measurements using the equation H° = arc (tangent b/a) where 0° = red, 90° = yellow and 180° = green.

4.2.5 Internal browning incidence and severity

In 2001 season export fruit was assessed only for incidence of internal browning (IB). Any IB regardless of the intensity of browning or percentage of flesh cut surface covered was recorded and the percentage of fruit affected calculated. In 2002 and 2003 seasons export fruit the incidence and severity of IB was recorded in export fruit. Severity was rated as 1 = none, 2 = trace, 3 = slight, 4 = moderate and 5 = severe (see Section 11.3.2. Plate 1).

5. SMARTFRESH^{TM}

5.1 SmartFresh^{TM} literature review

SmartFresh^{TM} [active ingredient 3.3% 1-methylcyclopropene (1-MCP)] is a gas that blocks the action of ethylene in plant tissue (Sisler et al. 1996a, b). SmartFresh^{TM} has been formulated as a powder that releases the active ingredient 1-MCP when mixed with water. It has a non-toxic mode of action similar to the naturally occurring plant substance, ethylene. In addition, residues in apples are less than 5 ppb, which is well below the level generally considered significant by regulatory authorities (SmartFresh^{TM} Apple Technical Bulletin).

SmartFresh^{TM} is being developed for use in fruit and vegetables by AgroFresh Inc. a wholly-owned subsidiary of the Rohm and Haas Company. SmartFresh^{TM} has been registered for use on apples in Australia (April 16th, 2004), the United States, Chile, Argentina, Mexico, New Zealand and South Africa (Turner, 2003).

Since ethylene is the plant growth regulator involved in fruit ripening, preventing its action by the use of SmartFresh^{TM} has the potential to extend storage life of horticultural products. SmartFresh^{TM} works by binding the active ingredient 1-MCP irreversibly to the ethylene binding sites of the plant. In apples it is thought after some time, new receptor sites are manufactured allowing the return of ethylene action and therefore normal ripening and senescence (Beaudry, 2003). The effects of SmartFresh^{TM} on apples are similar to those of controlled atmosphere (CA) which suppresses ethylene production and action, resulting in preservation of firmness and titratable acidity (Anderson and Abbot, 1975; Knee, 1976).

SmartFresh^{TM} should be added as soon as possible after harvest before the climacteric peak of respiration has occurred (SmartFresh^{TM} Apple Technical Bulletin). The rate of ethylene production in apples is low and fairly constant in preclimacteric fruit but as the fruit commences ripening there is an abrupt increase in the rate of production of ethylene, known as the climacteric. To realise maximum benefit of SmartFresh^{TM} fruit should be harvested at optimum quality which is slightly before or just after ripening has begun. AgroFresh Inc. recommends that the interval between harvest and storage be no longer than 7 – 14 days. Cooling fruit in accordance with standard commercial practices remains critical to quality and should continue to form part of the storage regime.

SmartFresh^{TM} is used at extremely low concentration 250 to 1000 parts per billion (ppb) in the airspace around the fruit. The time needed for effective treatment is relatively short 12 to 16 hours at 0°C to 20°C (Beaudry 2003). AgroFresh Inc. recommends a single application for 24 hours (SmartFresh^{TM} Apple Technical Bulletin). It is thought that better responses to SmartFresh^{TM} are obtained when fruit are treated warm on the day of harvest (Watkins, 2000). However, until we know more about SmartFresh^{TM} it is best to cool the fruit before applying the treatment. At this stage normal storage temperatures are recommended for storage of SmartFresh^{TM} treated fruit (Watkins et al. , 2000).

SmartFresh^{TM} substantially reduces the loss of apple flesh firmness (Blankenship and Unrath, 1998, Pre-Aymard et al. 2003, Fan et al. 1999a; Fan et al. 1999b; Mir et al. 2001), Rupasinghe et al. 2000, Watkins et al. 2002, Zanella, 2003) and also titratable acidity of different cultivars of preclimacteric and climacteric apples after long-term cool-storage and reduces respiration rate and ethylene production (Fan et al. 1999a).

A single postharvest treatment of SmartFresh^{TM} can prevent ripening for an extended period (greater than 30 days) at ambient (23.9^{o}C) temperature relative to non-treated controls (Beaudry 2003). Firmness of apples treated with SmartFresh^{TM} stored in regular air (RA) was statistically equivalent to untreated CA, the current industry standard for storing apples (Warner et al. 2002).

However, Watkins et al.(2000) reported the effect of SmartFresh^{TM} was greater in controlled atmosphere than in air storage. Apples treated with SmartFresh^{TM} combined with CA storage consistently outturn with higher firmness, titratable acidity and sugars after 6 months storage plus 7 days ripening at room temperature compared to CA alone (Warner et al. 2002).

SmartFresh^{TM} eliminates or substantially reduces physiological disorders of apple fruit during storage such as superficial scald, soft scald, core flush and greasiness (Rupasinghe et. al., 2000; Watkins et al. 2000; Kreidl et al. 2003, Zanella, 2001, Fan et al. 1999b).

SmartFresh^{TM} provides very good control of superficial scald at very low concentrations. There is strong evidence that α-farnesene is involved in scald development. Ethylene plays a part in regulating α-farnesene biosynthesis during fruit ripening and there are correlations between increasing internal ethylene and α-farnesene production (Ju and Curry, 2000). As well as inhibiting ethylene action 1-MCP is reported to delay or reduce the accumulation of α-farnesene and its oxidation products (Watkins *et al.* 2000). This would therefore lead to a delay in scald development.

The most common current chemical treatment for controlling superficial scald is diphenylamine (DPA). However, caution must be taken in substituting SmartFresh^{TM} for diphenylamine (DPA) to control superficial scald for all varieties (Watkins, 2002). In terms of scald control SmartFresh^{TM} needs to be monitored over several seasons before it can be recommended as a replacement for DPA.

Production of ripe aromas is stimulated by ethylene during apple fruit ripening (Mattheis et al. 2002). Fruit treated with SmartFresh^{TM} have delayed production of many compounds that impart ripe, fruity aromas and contribute to characteristic flavour. SmartFresh^{TM} reduces volatile production of apple fruits (Song et al. 1997) and inhibits differentially the production of many volatiles alcohols and esters in climacteric 'Fuji' apples compared to methyl jasmonate (Fan and Mattheis, 1999c). The effect of SmartFresh^{TM} is similar in magnitude to that induced by long-term CA. However, production of ripe aroma declines rapidly after SmartFresh^{TM} treatment compared to effects of CA, which takes several months to develop. SmartFresh^{TM} treated fruit maintain the fresh green aromas. How important ripe aromas are to the consumer needs to be established. For example, the absence of ripe aromas is potentially more important for Gala than for Granny Smith. Lurie et al. (2002) reported that Anna apples treated with 1µl /L 1-MCP developed less ripe aromas than control fruit or fruit treated with 0.1µl /L 1-MCP, although the consumer preference was for the fruit treated with the higher concentration. Therefore, while the impact of SmartFresh^{TM} on ripe aroma production is pronounced, it remains to be demonstrated how this impacts on marketability of fruit on a cultivar by cultivar basis.

One big concern about SmartFresh^{TM} is that fruit that are harvested too early may fail to develop flavour (Watkins, 2000). However, this does not mean that fruit should be picked over-mature. The great temptation for growers will be to pick fruit later with redder skin colour and size and then treat them with SmartFresh^{TM}. But until we know more about the impact of harvest maturity on eating quality it is suggested that apples should be harvested as per normal best practice for long term CA storage.

SmartFresh^{TM} substantially improves quality of apples stored for at least 2 months in air, and therefore has the potential to improve the quality of air-stored fruit presented to the consumer (Watkins, 2002).

Apples lose quality during shipment if the fruit is mishandled or particularly when displayed at retail without refrigeration (Mattheis et al. 2002). While SmartFresh^{TM} is not a replacement for refrigeration for prolonged storage, apple quality will deteriorate slower under sub-optimal temperature conditions if previously treated with SmartFresh^{TM}.

A major potential benefit of SmartFresh^{TM} will be in maintaining apple firmness post storage during shipping. Red Delicious apples that were stored for 140 days in CA at 0.6°C followed by 4 weeks at 0°C plus 7 days at 20°C remained firmer than non-treated fruit (SmartFresh^{TM} Apple Technical Bulletin).

SmartFresh^{TM} has been reported to increase the risk of CO_2 injury in sensitive cultivars (Watkins, 2002). However, if the CO_2 level is maintained low during the first 4 weeks of storage this should not be a problem.

The Tracking Pink Lady apple project has conducted a series of experiments during the past three years, to establish the benefits of SmartFresh^{TM} on maintaining fruit firmness after long-term air and CA storage, after simulated and actual shipments of fruit to the UK. Scientific Horticulture P/L conducted trials with Jonagold and Gala apples. The results, conclusions, discussion and recommendations of this body of SmartFresh^{TM} work are presented as follows.

5.2 Effect of SmartFresh^{TM} on the firmness of Pink Lady apples

INTRODUCTION

Premature softening of Pink Lady apples in storage or during sea-freight export has been identified by the industry as a significant problem. This was reflected in 1998 and 1999 when some shipments of Pink Lady apples to the UK were rejected or down graded because the fruit was too soft. The unreliability of Australian Pink Lady apples arriving in the UK forced some suppliers to stop exporting. UK consumers are prepared to pay a premium for Australian Pink Lady apples but continued quality failures may force the insurance companies to increase the cost of insurance premiums to a level where export is not a viable option.

Large numbers of Pink Lady apple trees are in the ground and most are not yet in full production. In three years time it is estimated that there will be an over supply of Pink Lady apples on the domestic market. The future success of Pink Lady apples hinges on export. Failure to fully develop export markets will see a significant downturn in the return for growers of Pink Lady apples.

If the Australian Pink Lady apple market share is to increase in the UK, it will require consistent, high quality apples.

SmartFresh^{TM} (1-methylcyclopropene or1-MCP) is a gas that can block the action of ethylene in harvested fruit. Preliminary storage trials overseas and at DPI, Knoxfield have demonstrated that apples treated with SmartFresh^{TM} before storage or before simulated sea-freight export can receive a significant beneficial effect by reducing apple softening. It was proposed to determine the benefits of treating Pink Lady apples before storage (air and CA), and before simulated sea-freight to maintain apple firmness. SmartFresh^{TM} is for use in the USA, New Zealand, Chile and Argentina for use on apples and it now registered in Australia.

This report summarises a series of trials conducted at DPI, Knoxfield in 2001, to establish the effect of 1-MCP on the storage life and quality of Pink Lady apples.

5.2.1 EXPERIMENTAL OBJECTIVES

Experiment 1(Parts 1 and 2). Effect of SmartFresh^{TM} treatment temperature and treatment time on the storage life and quality of Pink Lady apples.

Determine the effect of harvest maturity, SmartFresh^{TM} treatment temperature and SmartFresh^{TM} treatment time on Pink Lady storage life and quality.

Experiment 2 (Parts 1, 2 and 3). SmartFresh^{TM} Pink Lady simulated shipment trial. Effect of treatment before and after storage.

Determine if Pink Lady apples treated with SmartFresh^{TM} immediately after harvest, after storage or a combination of both, outturn firmer than untreated fruit.

Experiment 3. SmartFresh^{TM} Pink Lady commercial shipment trial. Effect of treatment and growing locality.

Determine the effect of treatment with SmartFresh^{TM} on Pink Lady apples collected from around Australia and incorporate the fruit after CA storage in an actual shipment to the UK where the fruit firmness will be assessed.

5.2.2 MATERIALS AND METHODS

Handling, SmartFresh^{TM} treatment, storage and simulated sea-freight and marketing

Experiment 1 (Part 1). Effect of SmartFresh^{TM} treatment temperature and treatment time on the storage life and quality of Pink Lady apples.

Harvest 1
Fruit was picked at grower one's orchard on the 11th April at the optimum harvest maturity for long term CA storage (starch score 4.8, firmness 9.1 kgf and TSS 14.1 °Brix). The fruit was transported to DPI, Knoxfield and placed at 2.5°C on the 11th April. 15 fruit were placed into nylon netting bags on the 14th April and then placed at 0°C. Three rooms were set at 4°C, 12°C or 20°C, each containing 16 treatment chambers. The treatment chamber consisted of 150-litre stainless steel base and a perspex lid, which was sealed by a water moat. Each treatment chamber contained a small air pump to create some air circulation. There were four treatment chambers per experimental block. The treatments were a control (0 ppb) and 10,000 ppb SmartFresh^{TM} by three treatment times and three temperatures. On the 15th April six bags of fruit were placed into each treatment chamber (3 bags for air storage and 3 bags for CA, allowing for three removal times 12, 16 and 20 weeks) at 4°C, 12°C or 20°C. The fruit pulp temperatures were at the room temperature when the SmartFresh^{TM} treatments commenced. SmartFresh^{TM} powder (3.3% active ingredient) was provided by Rohm and Haas Ltd. The manufacturer provided the weight of 1-MCP powder needed to provide a specific concentration of SmartFresh^{TM} gas in a given volume of air. In addition, 50 ml of potassium hydroxide (20% w/v) was placed in the chambers to absorb carbon dioxide. SmartFresh^{TM} was weighed into glass vials and taped to the perspex lid below an injection port. Water at room temperature was injected into the vials containing SmartFresh^{TM} powder at a rate of 16 ml per gram of SmartFresh^{TM}. The fruit was treated for 12, 24 or 48 hours at 4°, 6° or 12°C, 24 hours at 12°C and 3, 6 or 12 hours at 20°C. The control fruit received no SmartFresh^{TM} were stored in an unsealed treatment chamber for 48 hours at 0°C, 24 hours at 12°C and 12 hours at 20°C. Fruit was then put in storage at 0°C in air or CA (2.5% O_2 : 2.0% CO_2) on the 20th April. The treatment times were synchronised to finish at the same time.

Two storage rooms both set at 0°C were used to store two experimental blocks. The storage blocks corresponded to the treatment blocks. The 6 bags per treatment chamber were separated for storage, three for air storage and three for CA storage. The three bags for 3 removal times were stored in separate CA chambers or for air-stored fruit in crates with a high humidity liner.

Harvest 2
Fruit was picked at grower one's orchard on the 18th April with a harvest maturity suitable for long term CA storage (starch score 5.5, firmness 9.2 kgf and TSS 14.5 °Brix). The fruit

was transported to DPI, Knoxfield and placed at 4°C on the 18th April. On the 20th April 15 fruit were placed into nylon netting bags and then placed at 4°C, 12°C or 20°C. The fruit pulp temperature was at the room temperature when the SmartFresh™ treatments commenced. The SmartFresh™ treatments were 0 ppb and 10,000 ppb. The treatment procedure, treatment temperatures, treatment times and storage were the same as described above. The fruit was placed in storage at 0°C in air or CA (2.5% O_2 : 2.0% CO_2) on the 23rd April.

Fruit quality was assessed after the simulated marketing period. That is, after 12, 16 or 20 weeks storage followed by 6 weeks simulated sea-freight export at 0°C and 6 days at 20°C to simulate marketing.

Experimental Design:

Two SmartFresh™ treatments (before storage) x 3 treatment temperatures x 3 treatment times x 2 storage atmospheres x 3 storage times x 1 simulated marketing time x 4 replicate blocks x 15 fruit per replicate.

SmartFresh™ concentration:	10,000 ppb or control (0 ppb).
Treatment time x temperature:	3, 6 and 12 hours at 20°C 6, 12 and 24 hours at 12°C 12, 24 and 48 hours at 4°C
Maturity at harvest:	Pick 1 (11th April) and Pick 2 (18th April) were suitable for long term CA.

Timing of treatment application: Before storage.

Storage atmosphere:	Air or Controlled atmosphere (2.5% O_2 : 2 CO_2).
Storage time and temperature:	12, 16 or 20 weeks storage at 0°C
Simulated market time and temperature:	6 days at 20°C.

Statistical Analysis

The data was analysed by analysis of variance (ANOVA) using Genstat version 5.4.2 software (All tests used the 5% significance level unless otherwise specified).

Experiment 1 (Part 2). Effect of SmartFresh™ treatment temperature and treatment time on the storage life and quality of Pink Lady apples.

Fruit was picked at grower one's orchard on the 27th April at commercial pick maturity suitable for medium term CA storage (starch score 7.5, firmness 8.3 kgf and TSS 14.5 °Brix). The fruit was transported to DPI, Knoxfield and placed at 0°C on the 27th April. On the 4th May 8 fruit were placed into nylon netting bags and then placed at 4°C, 12°C or 20°C and the 1-MCP treatment (0 ppb and 1,000 ppb for 12 hours) applied. The fruit pulp temperature was at room temperature when the SmartFresh™ treatments commenced. A SmartFresh™ stock concentrate of 10,000,000 ppb was prepared and 15 ml of the concentrate was injected into the treatment chambers. 15ml of saturated ammonium sulphate was injected into the concentrate flask to standardise the volume and pressure. The fruit was placed at 0°C in CA (2.5% O_2 : 2.0% CO_2) on the 8th May.

In addition, fruit was treated with SmartFresh™ (0 ppb and 1000 ppb) for 12 hours at 20°C or 48 hours at 4°C after which the fruit was stored in air for 16 weeks at 0°C.

Fruit quality was assessed after the simulated marketing period. That is, after 16 weeks storage followed by 6 weeks simulated sea-freight at 0°C and 6 days at 20°C to simulate marketing.

Experimental Design:

For CA stored fruit:
Two SmartFresh™ treatments x 3 treatment temperatures x 1 treatment time x 1 storage atmosphere x 1 storage time x 1 sea-freight time x 6 replicate blocks x 8 fruit per replicate.

For air stored fruit:
Two SmartFresh™ treatments x 2 treatment times x 1 storage atmosphere x 1 storage time x 1 sea-freight time x 6 replicate blocks x 8 fruit pre replicate

For air and CA stored fruit:

SmartFresh™ concentration:	1,000 ppb or control (0 ppb)
Treatment time:	CA: 12 hours Air: 12 hours or 48 hours
Treatment temperature:	CA: 4°C, 12°C or 20°C Air: 20°C for 12 hour treatment time or 4°C for 48 hour treatment time
Maturity at harvest:	Late pick (27th April) suitable for medium term CA
Timing of treatment application:	Before storage
Storage atmosphere:	Air or Controlled atmosphere (2.5% O_2 : 2% CO_2)
Storage time and temperature:	16 weeks storage at 0°C
Simulated market time and temperature:	6 days at 20°C

Statistical Analysis

The data was analysed by analysis of variance (ANOVA) using Genstat version 5.4.2 software. (All tests used the 5% significance level unless otherwise specified).

Experiment 2 (Part 1). SmartFresh™ Pink Lady simulated shipment trial. Effect of treatment before storage.

Fruit was picked on the 26th April from growers two and threes' orchards. Fruit picked at grower two's orchard was at a commercial pick maturity suitable for medium term CA storage (starch score 7.6, firmness 8.4 kgf and TSS 14.6 °Brix). Fruit picked at grower three's orchard was at commercial pick maturity suitable for medium term CA storage (starch score 7.6, firmness 9.0 kgf and TSS 16.4 °Brix). The fruit was stored at 0°C overnight in a commercial store before being transported on the 27th April to DPI, Knoxfield and placed at 4°C.

On the 2nd May the fruit pulp temperature was warmed to 20°C before commencing the SmartFresh™ treatment (1000 ppb for 14 hour treatment).

The fruit was prepared for the SmartFresh™ treatment by placing 15 fruit in nylon netted bags. Two bags of 15 fruit were placed into each of 5 treatment chambers to provide fruit for storage in air and CA at 0°C. Control untreated fruit were in unsealed treatment chambers during treatment. A SmartFresh™ stock concentrate of 10,000,000 ppb was prepared and 15 ml of the concentrate was injected into the treatment chambers. 15ml of saturated ammonium sulphate was injected into the concentrate flask to standardise the volume and pressure.

On the 3rd May the fruit was returned to 0°C for the air and CA storage phase. CA storage commenced on the 4th May.

Fruit quality was assessed after the simulated marketing period. This is, after 12 weeks air storage or 18 weeks CA storage, followed by 6 weeks simulated sea-freight and 1 day at 20°C simulated marketing.

Experimental Design:

Two SmartFresh™ treatments (before storage) x 2 storage atmospheres x 1 storage time x 1 sea-freight time x 2 simulated sea-freight temperatures x 5 replicate blocks x 15 fruit per replicate.

Treatments:

SmartFresh™ concentration:	0 ppb or 1,000 ppb.
Maturity at harvest:	Late pick (26th April) suitable for medium term CA.
Treatment time:	14 hours.
Treatment temperature:	20°C.
Storage atmosphere:	Air or Controlled atmosphere (2.5% O_2 : 2% CO_2).

Storage time:	12 weeks for air storage and 18 weeks for CA stored fruit.
Simulated sea-freight temperature:	0°C or 4°C.
Simulated sea-freight time:	6 weeks.
Simulated marketing time and temperature:	1 day at 20°C.
Sea-freight atmosphere:	Air.

Statistical Analysis

The data was analysed by analysis of variance (ANOVA) using Genstat version 5.4. 2 software. (All tests used the 5% significance level unless otherwise specified).

Experiment 2 (Part 2). SmartFresh^{TM} Pink Lady simulated shipment trial. Effect of treatment before and after storage.

Fruit was picked at grower two's orchard on the 17thApril with a harvest maturity suitable for long term CA storage (starch score 5.1, firmness 8.7 kgf and TSS 13.4 °Brix). The fruit was transported to DPI, Knoxfield and was placed at 0°C on the 17th April. On the 19th April 15 fruit were placed in nylon netting bags at room temperature. The fruit pulp temperature was approximately 20°C when the SmartFresh^{TM} treatment (10,000 ppb for 14 hours) commenced on the 19th April. The SmartFresh^{TM} powder in the glass vial technique was used to administer the 1-MCP. The fruit was placed at 0°C in air or CA (2.5% O_2 : 2.0% CO_2) on the 20th April.

The following treatment combinations were applied:

1. Fruit with or without SmartFresh^{TM} applied before storage in air and CA for 16 weeks followed by 6 weeks simulated sea-freight in air at 0°C and 6 day at 20°C to simulate marketing.
2. Fruit with or without SmartFresh^{TM} applied before storage in air and CA, followed by a pre-shipment treatment with or without SmartFresh^{TM} (1000 ppb for 18 hours at 4°C), followed by 6 weeks simulated sea-freight in air at 0°C and 6 days at 20°C to simulate marketing.
3. Fruit with or without SmartFresh^{TM} applied before storage in CA, followed by 6 weeks simulated sea-freight in air or CA (2.5% O_2 : 2.0% CO_2) at 0°C and 6 days at 20°C to simulate marketing.

After treatment the three CA storage treatment combinations were randomised and allocated to one of three CA tubs per block (4 blocks in total). The air storage treatment combinations were stored in perforated plastic bags to maintain a high humidity air environment and placed on top of their matching CA treatments.

Fruit quality was only assessed after the simulated marketing period. This is, after 16 weeks storage, followed by 6 weeks at 2°C to simulate sea-freight and 6 days at 20°C to simulate marketing.

Experimental Design:

Two SmartFresh™ treatments x 2 storage atmospheres x 1 storage time x 1 sea-freight time x 1 simulated sea-freight temperature x 2 pre-ship SmartFresh™ treatments x 2 sea-freight atmosphere x 4 replicates x 15 fruit per replicate.

Treatments:

SmartFresh™ concentration:	0 ppb or 10,000 ppb (before storage). 0 ppb or 1,000 ppb (pre-shipment) after storage.
Maturity at harvest:	Optimal suitable for long term CA (Date 11th April).
Treatment time:	14 hours (before storage). 18 hours (pre-shipment).
Treatment temperature:	20°C (before storage). 4°C (pre-shipment).
Storage atmosphere:	Air or Controlled atmosphere (2.5% O_2 : 2% CO_2).
Storage time:	16 weeks
Simulated sea-freight temperature:	2°C.
Simulated sea-freight time:	6 weeks
Sea-freight atmosphere:	Air or Controlled atmosphere (2.5% O_2 : 2% CO_2).
Marketing time and temperature:	6 days at 20°C.

Statistical Analysis

The data was analysed by analysis of variance (ANOVA) using Genstat version 5.4. 2 software. (All tests used the 5% significance level unless otherwise specified).

Experiment 2 (Part 3). SmartFresh™ Pink Lady simulated shipment trial. Effect of treatment before and after storage.

Fruit was picked at grower two's orchard on the 26th April with a harvest maturity suitable for medium term CA storage (starch score 7.6, firmness 8.1 kgf and TSS 14.6 °Brix). The fruit was transported to IHD, Knoxfield and was placed at 0°C on the 27th April. On the 7th May 15 fruit were placed in nylon netting bags, at room temperature and returned to 0°C. On the 8th May the SmartFresh™ treatment (1,000 ppb for 14 hours) commenced. The fruit pulp temperature was approximately 20°C when the treatment commenced. The SmartFresh™ gas injection technique was used to administer SmartFresh™ as described above (see Experiment 1, Part 2). The fruit was placed at 0°C in air or CA (2.5% O_2 : 2.0% CO_2) on the 9th May.

The treatment combinations were the same as described above for experiment 2 (Part 2). After 16 weeks storage all treatment combinations were transferred to 4°C for 18 hours during the pre-shipment SmartFresh™ treatment period. The exceptions being the treatment, fruit with or without SmartFresh™ stored in CA followed by simulated CA sea-freight which were transferred to 2°C.

Fruit quality was only assessed after the simulated marketing period. That is, after16 weeks storage, followed by 6 weeks-simulated sea-freight at 2°C plus 6 days at 20°C to simulate marketing.

Experimental Design:

Two SmartFresh™ treatments (before storage) x 2 storage atmospheres x 1 storage time x 1 sea-freight time x 1 simulated sea-freight temperature x 2 pre-ship 1-MCP x 2 sea-freight atmosphere x 4 replicates x 15 fruit per replicate.

Treatments:

SmartFresh™ concentration:	0 ppb or 1,000 ppb.
Maturity at harvest:	Late pick (26th April) suitable for medium term CA.
Treatment time:	14 hours.
Treatment temperature:	20°C.
Storage atmosphere:	Air or Controlled atmosphere (2.5% O_2 : 2% CO_2).
Storage time:	16 weeks.
Simulated sea-freight temperature:	2°C .
Simulated sea-freight time:	6 weeks
Sea-freight atmosphere:	Air or Controlled atmosphere (2.5% O_2 : 2% CO_2).
Marketing time and temperature:	6 days at 20°C.

Statistical Analysis

The data was analysed by analysis of variance (ANOVA) using Genstat version 5.4. 2 software. (All tests used the 5% significance level unless otherwise specified).

Experiment 3. SmartFresh™ Pink Lady commercial shipment trial. Effect of treatment and growing locality.

Eight cartons of Pink Lady apples were supplied by growers from six regions within Australia. The fruit was picked at commercial harvest maturity. Fruit from grower 4 (Victoria) arrived 2/5/01, grower 5 (South Australia) arrived 7/5/01, grower 6 (South Australia) arrived 7/5/01, grower 7 (Victoria) arrived 17/5/01, grower 8 (Tasmania) arrived 21/5/01 and grower 9 (Western Australia) arrived 21/6/01. Four export cartons were treated on arrival at DPI, Knoxfield with SmartFresh™ (1000 ppb for 14 hours at 20°C) and four were untreated. After treatment the 1-MCP treated and untreated cartons were placed in CA (2.5% O_2 : 2.0% CO_2).

On the 12th September the export cartons were transported non-refrigerated to Tatura. The travel time was approximately 3 hours. On arrival the fruit was placed in a 0°C cool room. On the 17th September the cartons were stowed into a sea-freight container as part of a commercial shipment to the UK.

Fruit quality of a sub-sample of six fruit per carton was assessed 3 weeks prior to sea-freight (24th August) to establish SmartFresh™ effect on fruit firmness. On arrival in the UK (24th October) the quality of 50 fruit was assessed per replicate carton.

Experimental Design: For each grower:

Two SmartFresh™ treatment (before storage) x 4 replicate cartons x 50 fruit per replicate.

Treatments:

SmartFresh™ concentration:	0 ppb or 1,000 ppb.
Maturity at harvest:	Commercial pick suitable for medium term CA.
Treatment time:	14 hours.
Treatment temperature:	20°C.
Storage atmosphere:	Controlled atmosphere (2.5% O_2 : 2% CO_2).
Storage time:	18 weeks (Note a sub-sample of fruit was assessed at 15 weeks to determine if the fruit was still suitable for shipment to the UK)
Actual sea-freight time:	6 weeks
Sea-freight atmosphere:	Air.

Statistical Analysis

The data was analysed by analysis of variance (ANOVA) using Genstat version 5.4. 2 software. (All tests used the 5% significance level unless otherwise specified).

Measurements and assessments

Temperature

Ambient air temperature was monitored continually during the storage period. The rooms were within ±0.5^{o}C of the set point.

Atmosphere

Carbon dioxide and oxygen levels inside the CA chambers were monitored and controlled by a Bishop Instrument gas analyser. Gas levels were maintained at
± 0.5% of the setpoint.

Quality

Fruit quality for each maturity was assessed before storage and after simulated marketing.

Initial fruit quality before each experiment was compared with respect to background colour, firmness and total soluble solids (TSS). The starch scores of the fruit were measured visually using the European 10 point scale pictorial guide (see Appendix A).

Background colour was measured using a Minolta CR200 chromameter using the white calibration tile (L= 97.3, a= -0.49, b= 1.91). The b-values and a-values measured by the chromameter were used to calculate the hue angle values. Hue angle was used to determine the change in ground colour greenness. Hue angle (h^o) = arc(tangent b/a) where 90^o = yellow and 180^o = green. Consequently, high h^o values indicate greener fruit. A hue angle value of 110 h^o represents green and 105 h^o represents green / yellow. Relatively small changes in h^o can represent a substantial visual change in the fruit background colour from green to yellow.

Flesh firmness, expressed as kilogram force (kgf) was measured using an Effigi penetrometer with an 11 mm plunger.

Total soluble solids (TSS) expressed as ^{o}Brix was measured using a digital refractometer.

Superficial scald was assessed on an incidence basis and recorded as a percentage of fruit affected.

All fruit quality assessments were conducted when the fruit had reached room temperature.

5.2.3. RESULTS

Experiment 1 (Part 1). Effect of SmartFresh^{TM} on the storage life and quality of Pink Lady apples.

In experiment 1 (Part 1) the apples from two harvest dates were treated with or without SmartFresh^{TM} at 10,000 ppb for 3 different treatment times for each temperature 4°C, 12°C or 20°C. All apples were stored for 12 weeks, 16 weeks or 20 weeks in air or CA at 0°C, followed by 6 weeks at 0°C to simulate sea-freight conditions, followed by 6 days at 20°C to simulate marketing.

Fruit quality after 12 weeks storage

Firmness
For fruit stored in air, the effects of SmartFresh^{TM} on firmness, at all treatment temperatures were significant with treated fruit firmer by 0.5 to 0.8 kgf (Table 1)*. For apples stored in CA, SmartFresh^{TM} had a significant effect on the firmness of fruit treated at 20°C but not on fruit treated at the lower temperatures.

There was no significant effect of treatment time on firmness at any treatment temperature, nor was there evidence of an interaction between harvest date, storage conditions and treatment temperatures (Data not shown).

Total soluble solids
For fruit stored either in air or CA, the effects of SmartFresh^{TM} on TSS at all 3 treatment temperatures was not significant (Table 2).

There was no significant effect of treatment time on total soluble solids at any treatment temperature, nor was there evidence of an interaction between harvest date, storage conditions and treatment temperatures (Data not shown).

Ground colour
For fruit stored in air, the effects of SmartFresh^{TM} on ground colour was only significant for treatment temperatures of 4°C and 12°C. SmartFresh^{TM} did not have a significant effect on the colour of CA stored apples at any treatment temperatures (Table 3).

There was no significant effect of treatment time on ground colour, nor was there evidence of an interaction between harvest date, storage conditions and treatment temperatures (Data not shown).

Fruit quality after16 weeks storage

Firmness
For fruit stored in air, the effect of SmartFresh^{TM} on firmness at 4°C and 20°C treatment temperatures was significant with treated fruit firmer by approximately 0.7 kgf (Table 4). There was no significant effect of SmartFresh^{TM} on firmness with the 12°C treatment temperature. For apples stored in CA, SmartFresh^{TM} only had a significant effect on the firmness of fruit treated at 12°C.

* All tables referenced are to be found within the current chapter.

There was no significant effect of treatment time on firmness, nor was there evidence of an interaction between harvest date, storage conditions and treatment temperatures (Data not shown).

Total soluble solids
SmartFresh^{TM} only had a significant effect on TSS content of fruit treated at 4°C and stored in air and treated at 20°C and stored in CA (Table 5).

There was no significant effect of treatment time on total soluble solids, nor was there evidence of an interaction between harvest date, storage conditions and treatment temperatures (Data not shown).

Ground colour
SmartFresh^{TM} had a significant effect in maintaining green ground colour of fruit treated at 4°C or 12°C and stored in air (Table 6). Both treated and untreated fruit stored in CA were significantly greener compared to fruit not treated and stored in air. Treated fruit stored in air were as green as treated and untreated fruit stored in CA. There was no significant effect of treatment time on ground colour, nor was there evidence of an interaction between harvest date, storage conditions and treatment temperatures (Data not shown).

Fruit quality after 20 weeks storage

Firmness
For fruit stored in air, the effect of SmartFresh^{TM} on firmness at all treatment temperatures was significant with treated fruit firmer by 0.7 kgf to 0.9 kgf (Table 7). For apples stored in CA, SmartFresh^{TM} had a significant effect on firmness at all 3 treatment temperatures with treated fruit 0.3 – 0.4 kgf firmer.

There was no significant effect of treatment time on firmness, nor was there evidence of an interaction between harvest date, storage conditions and treatment temperatures (Data not shown).

Total soluble solids
The effect of SmartFresh^{TM} on total soluble solids content of fruit stored in air or CA, at all 3 treatment temperatures was not significant (Table 8). The only exception being for fruit stored in air and treated at 12°C which had an increased total soluble solids content of 0.5 °Brix.

There was no significant effect of treatment time on total soluble solids, nor was there evidence of an interaction between harvest date, storage conditions and treatment temperatures (Data not shown).

Ground colour
The effect of SmartFresh^{TM} on ground colour of fruit treated at all 3 treatment temperatures and stored in air or CA was not significant (Table 9). However, untreated fruit stored in CA were significantly greener compared to untreated fruit stored in air. Treated fruit treated at 4°C and 12°C and stored in CA were significantly greener than untreated fruit stored in CA.

There was no significant difference between untreated fruit and treated fruit treated at 20°C and stored in air or CA.

There was no significant effect of treatment time on ground colour, nor was there evidence of an interaction between harvest date, storage conditions and treatment temperatures (Data not shown).

Experiment 1 (Part 2). Effect of SmartFresh^{TM} on the storage life and quality of Pink Lady apples.

In experiment 1 (Part 2), the apples were treated with or without SmartFresh^{TM} at 1,000 ppb. CA (2.5% O_2 : 2.0% CO_2) stored fruit were treated for 12hours at 4°C, 12°C or 20°C whereas air stored fruit were treated for either 48 hours at 4°C or 12 hours at 20°C. All apples were stored for 16 weeks at 0°C, followed by 6 weeks at 0°C to simulate sea-freight conditions, followed by 6 days at 20°C to simulate marketing.

Firmness
The effect of SmartFresh^{TM} on Pink Lady apple firmness after 16 weeks storage in CA was significant for fruit treated at 12°C and 20°C (Table 10). SmartFresh^{TM} treated fruit were approximately 0.4 kgf firmer than untreated fruit.

For fruit stored in air, the effect of SmartFresh^{TM} treatment for 48 hours at 4°C on firmness was significant (Table 11). SmartFresh^{TM} treated fruit were approximately 0.8 kgf firmer than untreated fruit.

For fruit stored in air, the effect of SmartFresh^{TM} treatment for 12 hours at 20°C on firmness was significant. SmartFresh^{TM} treated fruit were approximately 1.0 kgf firmer than untreated fruit.

Total soluble solids
The effect of SmartFresh^{TM} on Pink Lady apple total soluble solids content after 16 weeks storage in CA was significant for the fruit treated at 20°C (Table 13).

For fruit stored in air, the effect of SmartFresh^{TM} treatment for 48 hours at 4°C on total soluble solids content was not significant (Table 14).

For fruit stored in air, the effect of SmartFresh^{TM} treatment for 12 hours at 20°C on total soluble solids content was not significant (Table 15).

Ground colour
The effect of SmartFresh^{TM} on Pink Lady apple ground colour after 16 weeks storage in CA was not significant for all 3 treatment temperatures (Table 16). There was no ground colour data available for air stored fruit.

Experiment 2 (Part 1). SmartFresh^{TM} Pink Lady simulated shipment trial. Effect of treatment before storage.

Apples were sourced from two growers and treated with SmartFresh^{TM} at 1,000 ppb or not treated for 14 hours at 20°C then stored in air for 12 weeks at 0°C or CA storage

(2.5% O_2 : 2.0% CO_2) for 18 weeks at 0°C. The apples were then kept for 6 weeks at either 0°C or 4°C to simulate sea-freight conditions, followed by 6 days at 20°C to simulate marketing.

Firmness
The overall effect of SmartFresh™ on Pink Lady apple firmness after 12 weeks storage in air was significant with an increase in fruit firmness of 0.9 kgf to 1.4 kgf for grower 2 and 3 respectively (Table 17). Fruit from grower 2 treated with SmartFresh™ and stored at 0°C was significantly firmer than fruit stored at 4°C. For grower 3, only untreated fruit stored at 0°C were significantly firmer than fruit stored at 4°C.

The effect of SmartFresh™ on Pink Lady apple firmness after 18 weeks storage in CA was significant for both simulated sea-freight temperatures with an increase in fruit firmness of 0.4 kgf for grower 3 but not grower 2 (Table 18). There was no significant effect of the two sea-freight temperatures on firmness.

Experiment 2 (Part 2). SmartFresh™ Pink Lady simulated shipment trial. Effect of treatment before and after storage.

In experiment 2 (Part 2), the apples were either treated with SmartFresh™ at 10,000 ppb or 0 ppb for 14 hours at 20°C before storage. The apples were stored in air or CA storage (2.5% O_2 : 2.0% CO_2) for 16 weeks at 0°C. The apples were then treated again or not treated with SmartFresh™ at 1,000 ppb for 18 hours at 4°C, followed by 6 weeks at 2°C in air or CA (2.5% O_2 : 2.0% CO_2) to simulate sea-freight conditions plus 6 days at 20°C to simulate marketing.

Firmness
The overall effect of SmartFresh™ on firmness was significant for fruit shipped in either air or CA with fruit firmer by 1.0 kgf and 0.5 kgf respectively (Table 19). Fruit treated with SmartFresh™ and shipped in air was 0.4 kgf firmer than untreated CA fruit, which was significant. Fruit not treated with SmartFresh™ and shipped in CA was 0.6 kgf firmer than untreated fruit shipped in air.

Treating fruit with SmartFresh™ again prior to sea-freight did not have a significant effect on fruit firmness (Table 20).

The overall effect of SmartFresh™ was to significantly increase fruit firmness for all storage and simulated sea-freight atmosphere combinations (Table 21). The firmness of fruit treated with SmartFresh™ and stored in air or CA and shipped in air were not significantly different to fruit stored in CA and shipped in CA. However, the firmness of fruit not treated with SmartFresh™ and stored in CA was significantly higher than untreated fruit stored in air. There was no significant difference in the firmness of fruit stored in CA and shipped in air or CA.

Total soluble solids
The effect of SmartFresh™ on total soluble solids content was significant for fruit shipped in air with TSS higher by 0.4 °Brix (Table 22). However, there was no significant effect on the fruit shipped in CA. The °Brix levels of fruit shipped in air and CA were not significantly different.

Re-treating fruit with SmartFresh^{TM} prior to sea-freight did not have a significant effect on total soluble solids content (Table 23).

The effect of SmartFresh^{TM} on total soluble solids content was significant if the fruit was stored in either air or CA and shipped in air with an increase of approximately 0.4 °Brix. The effect was not significant if the fruit was shipped in CA (Table 24). The total soluble solids content of fruit treated with SmartFresh^{TM} and stored in either air or CA and shipped in air was not significantly different to fruit stored in CA and shipped in CA. There was no significant difference in the total soluble solids content of fruit stored in CA and then shipped in air or CA.

Ground colour

The effect of SmartFresh^{TM} on ground colour was significant for fruit shipped in air but not for fruit shipped in CA (Table 25). Fruit shipped in CA and not treated with SmartFresh^{TM} were significantly greener compared to fruit shipped in air.

Treating fruit with SmartFresh^{TM} prior to sea-freight did not have a significant effect on ground colour (Table 26).

The effect of SmartFresh^{TM} on ground colour was significant if the fruit was stored in CA and then shipped in air but not if it was stored and shipped in CA or stored in air and shipped in air (Table 27). There was no significant difference in the ground colour of treated fruit stored in CA and shipped in air compared to treated fruit stored in CA and then shipped in CA. Treated fruit stored in CA and shipped in air or CA were greener than treated fruit stored in air and shipped in air.

Experiment 2 (Part 3). SmartFresh^{TM} Pink Lady simulated shipment trial. Effect of treatment before and after storage.

In experiment 2 (Part 3), the apples were either treated with SmartFresh^{TM} at 1,000 ppb or not for 14 hours at 20°C before storage. The apples were then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 16 weeks at 0°C. The apples were either treated again or not treated with SmartFresh^{TM} at 1,000 ppb for 18 hours at 4°C and then stored for by 6 weeks at 2°C in either air or CA (2.5% O_2 : 2.0% CO_2) to simulate sea-freight conditions plus 6 days at 20°C to simulate marketing.

Firmness

The effect of SmartFresh^{TM} on firmness was significant with treated fruit shipped in air and CA, firmer by 1.2 kgf and 0.6 kgf respectively (Table 28). Fruit not treated with SmartFresh^{TM} and shipped in CA were 0.6 kgf firmer than to fruit shipped in air. Fruit treated with SmartFresh^{TM} and shipped in air was not significantly different to treated fruit shipped in CA. Untreated fruit shipped in CA was 0.6 kgf firmer than untreated fruit shipped in air.

The effect of re-treating fruit with SmartFresh^{TM}, prior to sea-freight was not significant on fruit firmness after shipment in either air or CA (Table 29).

The overall effect of SmartFresh^{TM} on fruit firmness was significant for all three storage and sea-freight atmosphere combinations (Table 30). For fruit treated with SmartFresh^{TM}, there was no significant difference in firmness between any of the atmosphere combinations. However, untreated fruit stored in CA and shipped in CA or air were significantly firmer compared to fruit stored in air and shipped in air.

Total soluble solids
The effect of SmartFresh^{TM} on total soluble solids content was significant for fruit shipped in air but not for CA (Table 31). Fruit treated with SmartFresh^{TM} shipped in air were not significantly different to fruit not treated and shipped in CA.

The effect of treating fruit again with SmartFresh^{TM}, prior to sea-freight was not significant on total soluble solids content (Table 32).

The effect of SmartFresh^{TM} on total soluble solids content was significant if the fruit was stored and shipped in air but not for the other CA and air combinations (Table 33).

Ground colour
The effect of SmartFresh^{TM} on ground colour was significant for fruit shipped in air but not for CA (Table 34). Fruit treated with SmartFresh^{TM} and shipped in air were not significantly different to fruit not treated and shipped in CA.

Treating fruit again with SmartFresh^{TM} prior to sea-freight did not have a significant effect on ground colour (Table 35).

The effect of SmartFresh^{TM} on ground colour was significant if the fruit was stored in air and shipped in air but not if it was stored in CA and shipped in CA or stored in CA and shipped in air (Table 36). Fruit treated with SmartFresh^{TM} and stored and shipped in CA was significantly greener than untreated fruit stored and shipped in air.

Superficial Scald
No scald was observed in CA stored fruit irrespective of 1-MCP treatment and only very low levels (0.9 - 1.8%) in air stored fruit not treated with 1-MCP (Data not shown).

Experiment 3. SmartFresh^{TM} Pink Lady commercial shipment trial. Effect of treatment and growing locality.

Firmness
Apples sourced from the Goulburn Valley (Growers 4 and 7), South Australia (Growers 5 and 6), Tasmania (Grower 8) and Western Australia (Grower 9) were treated with 1-MCP at 1,000 ppb or not for 14 hours at 20°C. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 15 weeks at 0°C and a sub-sample of the fruit was assessed to determine if the fruit was suitable to send to the UK. After 18 weeks storage the apples were shipped to the UK where the fruit was assessed again.

The effect of SmartFresh^{TM} on fruit firmness was significant for fruit sourced from the Goulburn Valley (Growers 4 and 7), South Australia (Growers 5 and 6) and Tasmania (Grower 8), with fruit firmer by 0.4 kgf to 1.2 kgf after 15 weeks storage at 0°C plus 6 days at 20°C (Table 37). For apples sourced from Western Australia (Grower 9) the effect of SmartFresh^{TM} was not significant, most likely due to the fruit being over mature based on the starch patterns of the fruit on arrival at DPI, Knoxfield. The Western Australian fruit was not sent to the UK because the fruit did not meet export quality. The apples assessed in the UK that were treated with SmartFresh^{TM} were significantly firmer than untreated fruit by 0.5 kgf to 1.3 kgf (Table 38).

5.2.7 TABLES

Experiment 1 (Part 1). Effect of SmartFresh™ on the storage life and quality of Pink Lady apples.

Table 1. Firmness of Pink Lady apples (12 weeks). The apples were treated with SmartFresh™ at 10,000 ppb or not at 3 different treatment temperatures. The apples were then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 12 weeks storage at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion) Storage conditions		Firmness (kgf)		
		Treatment temperature		
		4°C	12°C	20°C
0 ppb	AIR	8.0	7.9	8.0
10,000 ppb	AIR	8.5	8.6	8.8
0 ppb	CA	8.6	8.5	8.5
10,000 ppb	CA	8.8	8.7	8.8
LSD (P=0.05)[1]		0.2[2]		
		0.3[3]		
		0.2[4]		

[1] Least significant difference of the means (5% level).
[2.] Comparing down columns.
[3.] Comparing across 0 ppb row.
[4.] Comparing across 10,000 ppb row.

Table 2. Total soluble solids content of Pink Lady apples (12 weeks). The apples were treated with SmartFresh™ at 10,000 ppb or not at 3 different treatment temperatures. The apples were then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 12 weeks storage at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion) Storage conditions		Total soluble solids °Brix		
		Treatment temperature		
		4°C	12°C	20°C
0 ppb	AIR	14.8	15.2	14.9
10,000 ppb	AIR	15.3	15.2	15.2
0 ppb	CA	15.3	15.2	15.1
10,000 ppb	CA	15.1	15.2	15.3
LSD (P=0.05)[1]		0.5[2]		
		0.6[3]		
		0.4[4]		

[1] Least significant difference of the means (5% level).
[2.] Comparing down columns.
[3.] Comparing across 0 ppb row.
[4.] Comparing across 10,000 ppb row.

Table 3. Ground colour of Pink Lady apples (12 weeks). The apples were treated with SmartFresh™ at 10,000 ppb or not at 3 different treatment temperatures. The apples were then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 12 weeks storage at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion) Storage conditions		Ground colour Hue angle °h Treatment temperature 4°C	12°C	20°C
0 ppb	AIR	99.0	98.6	100.9
10,000 ppb	AIR	101.4	101.1	100.4
0 ppb	CA	101.2	101.6	102.6
10,000 ppb	CA	101.6	103.8	102.5
LSD (P=0.05)[1]		2.3[2]		
		2.4[3]		
		1.3[4]		

[1] Least significant difference of the means (5% level).
[2.] Comparing down columns.
[3.] Comparing across 0 ppb row.
[4.] Comparing across 10,000 ppb row.

Table 4. Firmness of Pink Lady apples (16 weeks). The apples were treated with SmartFresh™ at 10,000 ppb or not at 3 different treatment temperatures. The apples were then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion) Storage conditions		Firmness (kgf) Treatment temperature 4°C	12°C	20°C
0 ppb	AIR	7.8	7.8	7.8
10,000 ppb	AIR	8.5	8.0	8.5
0 ppb	CA	8.3	8.3	8.2
10,000 ppb	CA	8.5	8.8	8.5
LSD (P=0.05)[1]		0.3[2]		
		0.4[3]		
		0.2[4]		

[1] Least significant difference of the means (5% level).
[2.] Comparing down columns.
[3.] Comparing across 0 ppb row.
[4.] Comparing across 10,000 ppb row.

Table 5. Total soluble solids content of Pink Lady apples (16 weeks). The apples were treated with SmartFresh™ at 10,000 ppb or not at 3 different treatment temperatures. The apples were then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)		Total soluble solids °Brix		
		Treatment temperature		
Storage conditions		4°C	12°C	20°C
0 ppb	AIR	15.2	15.4	15.2
10,000 ppb	AIR	15.6	15.6	15.3
0 ppb	CA	15.5	15.2	15.1
10,000 ppb	CA	15.2	15.2	15.5
LSD (P=0.05)[1]		0.3[2]		
		0.4[3]		
		0.3[4]		

[1] Least significant difference of the means (5% level).
[2.] Comparing down columns.
[3.] Comparing across 0 ppb row.
[4.] Comparing across 10,000 ppb row.

Table 6. Ground colour of Pink Lady apples (16 weeks). The apples were treated with SmartFresh™ at 10,000 ppb or not at 3 different treatment temperatures. The apples were then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)		Ground colour Hue angle °h		
		Treatment temperature		
Storage conditions		4°C	12°C	20°C
0 ppb	AIR	99.2	99.6	99.3
10,000 ppb	AIR	102.2	102.3	101.0
0 ppb	CA	102.1	102.6	102.3
10,000 ppb	CA	102.1	103.1	103.0
LSD (P=0.05)[1]		2.4[2]		
		2.8[3]		
		1.9[4]		

[1] Least significant difference of the means (5% level).
[2.] Comparing down columns.
[3.] Comparing across 0 ppb row.
[4.] Comparing across 10,000 ppb row.

Table 7. Firmness of Pink Lady apples (20 weeks). The apples were treated with SmartFresh™ at 10,000 ppb or not at 3 different treatment temperatures. The apples were then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 20 weeks storage at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion) Storage conditions		Firmness (kgf)		
		Treatment temperature		
		4°C	12°C	20°C
0 ppb	AIR	7.8	7.7	7.6
10,000 ppb	AIR	8.5	8.4	8.5
0 ppb	CA	8.0	8.0	8.2
10,000 ppb	CA	8.4	8.3	8.6
LSD (P=0.05)[1]		0.2[2]		
		0.3[3]		
		0.1[4]		

[1] Least significant difference of the means (5% level).
[2.] Comparing down columns.
[3.] Comparing across 0 ppb row.
[4.] Comparing across 10,000 ppb row.

Table 8. Total soluble solids content of Pink Lady apples (20 weeks). The apples were treated with SmartFresh™ at 10,000 ppb or not at 3 different treatment temperatures. The apples were then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 20 weeks storage at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion) Storage conditions		Total soluble solids °Brix		
		Treatment temperature		
		4°C	12°C	20°C
0 ppb	AIR	15.6	15.2	15.2
10,000 ppb	AIR	15.5	15.7	15.4
0 ppb	CA	15.3	15.2	15.3
10,000 ppb	CA	15.4	15.4	15.4
LSD (P=0.05)[1]		0.3[2]		
		0.4[3]		
		0.2[4]		

[1] Least significant difference of the means (5% level).
[2.] Comparing down columns.
[3.] Comparing across 0 ppb row.
[4.] Comparing across 10,000 ppb row.

Table 9. Ground colour of Pink Lady apples (20 weeks). The apples were treated with SmartFresh™ at 10,000 ppb or not at 3 different treatment temperatures. The apples then stored in air or CA (2.5% O_2 : 2.0% CO_2) for 20 weeks at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion) Storage conditions		Ground colour Hue angle °h Treatment temperature 4°C	12°C	20°C
0 ppb	AIR	99.8	100.8	100.5
10,000 ppb	AIR	100.5	99.9	102.5
0 ppb	CA	102.9	103.9	103.6
10,000 ppb	CA	103.6	103.8	102.4
LSD (P=0.05)[1]		3.0[2]		
		3.4[3]		
		2.7[4]		

[1] Least significant difference of the means (5% level).
[2] Comparing down columns.
[3] Comparing across 0 ppb row.
[4] Comparing across 10,000 ppb row.

Experiment 1 (Part 2). Effect of SmartFresh™ on the storage life and quality of Pink Lady apples.

Table 10. Firmness of Pink Lady apples (16 weeks). The apples were treated with SmartFresh™ at 1,000 ppb or not for 12 hours at 3 different treatment temperatures. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks at 0°C, followed by 6 weeks at 0°C simulated sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Firmness (kgf) Treatment temperature 4°C	12°C	20°C
0 ppb	7.8	7.8	7.6
1000 ppb	8.0	8.1	8.0
LSD (P=0.05)[1]	0.2		

[1] Least significant difference of the means (5% level).

Table 11. Firmness of Pink Lady apples (16 weeks). The apples were treated with SmartFresh^{TM} at 1,000 ppb or not at 4°C for 48 hours. The apples were then stored in air for 16 weeks at 0°C, followed by 6 weeks at 0°C simulated sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh^{TM} concentration (ppb = parts per billion)	Firmness (kgf)
0 ppb	7.5
1000 ppb	8.3
LSD (*P*=0.05)[1]	0.3

[1] Least significant difference of the means (5% level).

Table 12. Firmness of Pink Lady apples (16 weeks). The apples were treated with SmartFresh^{TM} at 1,000 ppb or not at 20°C for 12 hours. The apples were then stored in air for 16 weeks at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh^{TM} concentration (ppb = parts per billion)	Firmness (kgf)
0 ppb	7.1
1000 ppb	8.1
LSD (*P*=0.05)[1]	0.3

[1] Least significant difference of the means (5% level).

Table 13. Total soluble solids content of Pink Lady apples (16 weeks). The apples were treated with SmartFresh^{TM} at 1,000 ppb or not for 12 hours at 3 different treatment temperatures. The apples then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh^{TM} concentration (ppb = parts per billion)	Total soluble solids (°Brix)		
	Treatment temperature		
	4°C	12°C	20°C
0 ppb	15.0	15.4	14.7
1000 ppb	15.1	15.5	15.2
LSD (*P*=0.05)[1]	0.4		

[1] Least significant difference of the means (5% level).

Table 14. Total soluble solids content of Pink Lady apples (16 weeks). The apples were treated with SmartFresh^{TM} at 1,000 ppb or not at 4°C for 48 hours. The apples were then stored in air for 16 weeks at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh^{TM} concentration (ppb = parts per billion)	Total soluble solids (°Brix)
0 ppb	15.4
1,000 ppb	15.5
LSD (*P*=0.05)[1]	1.0

[1] Least significant difference of the means (5% level).

Table 15. Total soluble solids content of Pink Lady apples (16 weeks). The apples were treated with SmartFresh^{TM} at 1,000 ppb or not at 20°C for 12 hours. The apples were then stored in air for 16 weeks at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh^{TM} concentration (ppb = parts per billion)	Total soluble solids (°Brix)
0 ppb	15.1
1000 ppb	15.0
LSD (*P*=0.05)[1]	0.4

[1] Least significant difference of the means (5% level).

Table 16. Ground colour of Pink Lady apples (16 weeks). The apples were treated with SmartFresh^{TM} at 1,000 ppb or not for 12 hours at 3 different treatment temperatures. The apples then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks at 0°C, followed by 6 weeks at 0°C to simulate sea-freight export followed by 6 days at 20°C to simulate marketing.

SmartFresh^{TM} concentration (ppb = parts per billion)	Ground colour hue angle (°h)		
	Treatment temperature		
	4°C	12°C	20°C
0 ppb	101.4	100.8	102.0
1000 ppb	102.4	100.3	100.6
LSD (*P*=0.05)[1]	2.2		

[1] Least significant difference of the means (5% level).

Experiment 2 (Part 1). SmartFresh™ Pink Lady simulated shipment trial. Effect of treatment before storage.

Table 17. Firmness of Pink Lady apples (12 weeks). The apples from 2 growers were either treated with SmartFresh™ at 1,000 ppb or not at 20°C for 14 hours before storage. The apples were then stored in air for 12 weeks at 0°C, followed by 6 weeks at 0°C or 4°C to simulate sea-freight conditions followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Firmness (kgf)			
	Grower 2		Grower 3	
Sea-freight temperature	0°C	4°C	0°C	4°C
0 ppb	7.0	6.7	7.3	6.9
1000 ppb	8.1	7.6	8.6	8.3
LSD (P=0.05)[1]	0.3[2]			
	0.6[3]			

[1] Least significant difference of the means (5% level).
[2.] Comparing across rows.
[3.] For all other comparisons.

Table 18. Firmness of Pink Lady apples (18 weeks). The apples from 2 growers were either treated with SmartFresh™ at 1,000 ppb or not at 20°C for 14 hours before storage. The apples were then stored in CA storage (2.5% O_2 : 2.0% CO_2) for 18 weeks at 0°C, followed by 6 weeks at either 0°C or 4°C to simulate sea-freight conditions followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Firmness (kgf)			
	Grower 2		Grower 3	
Sea-freight temperature	0°C	4°C	0°C	4°C
0 ppb	7.5	7.4	7.8	7.8
1000 ppb	7.6	7.7	8.2	8.2
LSD (P=0.05)[1]	0.3			

[1] Least significant difference of the means (5% level).

Experiment 2 (Part 2).SmartFresh™ Pink Lady simulated shipment trial. Effect of treatment before and after storage.

Table 19. Firmness of Pink Lady apples. The apples were either treated with SmartFresh™ at 10,000 ppb or not for 14 hours at 20°C before storage. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C, followed by 6 weeks at 2°C to simulate sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Firmness (kgf)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
0 ppb	7.0	7.6
10,000 ppb	8.0	8.1
LSD (P=0.05)[1]	0.2[2]	
	0.3[3]	
	0.3[4]	

[1] Least significant difference of the means (5% level).
[2] Comparing down the air columns.
[3] Comparing down the CA columns.
[4] For all other comparisons.

Table 20. Firmness of Pink Lady apples. The apples were either treated with SmartFresh™ at 10,000 ppb for 14 hours at 20°C before storage. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C. The apples were then retreated or not with 1-MCP at 1,000 ppb for 18 hours at 4°C (pre-shipment treatment), followed by 6 weeks at 2°C simulated sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

Pre-shipment treatment	SmartFresh™	Firmness (kgf)	
		Sea-freight atmosphere	
		Air	Controlled atmosphere
Pre-ship SmartFresh™	0 ppb	7.5	7.8
Pre-ship SmartFresh™	1000 ppb	7.5	-[2]
LSD (P=0.05)[1]		0.2	

[1] Least significant difference of the means (5% level).
[2] No data available.

Table 21. Firmness of Pink Lady apples. The apples were either treated with SmartFresh™ at 10,000 ppb or not for 14 hours at 20°C before storage. The apples were then stored in either air or CA (2.5% O_2 plus 2.0% CO_2) for 16 weeks at 0°C The apples were stored for 6 weeks at 2°C in either air or CA (2.5% O_2 plus 2.0% CO_2) to simulate sea-freight conditions plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Firmness (kgf)		
	Land-based to Sea-freight atmosphere		
	Air to air	CA to air	CA to CA
0 ppb	6.6	7.5	7.6
10,000 ppb	8.0	8.0	8.1
LSD (P=0.05)[1]	0.2[2]		
	0.3[3]		
	0.3[4]		

[1] Least significant difference of the means (5% level).
[2.] Comparing down the air to air columns.
[3.] Comparing down the CA to Ca columns.
[4.] For all other comparisons

Table 22. Total soluble solids content of Pink Lady apples. The apples were either treated with SmartFresh™ at 10,000 ppb or not for 14 hours at 20°C before storage. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C, followed by 6 weeks at 2°C to simulate sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Total soluble solids (°Brix)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
0 ppb	14.1	14.1
10,000 ppb	14.5	14.3
LSD (P=0.05)[1]	0.[2]2	
	0.3[3]	
	0.3[4]	

[1] Least significant difference of the means (5% level).
[2] Comparing down the air columns.
[3.] Comparing down the CA columns.
[4.] For all other comparisons.

Table 23. Total soluble solids content of Pink Lady apples. The apples were either treated with SmartFresh^{TM} at 10,000 ppb for 14 hours at 20°C before storage. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C. The apples were then retreated or not with 1-MCP at 1,000 ppb for 18 hours at 4°C (pre-shipment treatment), followed by 6 weeks at 2°C simulated sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

Pre-shipment treatment	SmartFresh^{TM}	Total soluble solids (°Brix)	
		Sea-freight atmosphere	
		Air	Controlled atmosphere
Pre-ship SmartFresh^{TM}	0 ppb	14.3	14.2
Pre-ship SmartFresh^{TM}	1000 ppb	14.3	-
LSD (P=0.05)[1]		0.2	

[1] Least significant difference of the means (5% level).

Table 24. Total soluble solids content of Pink Lady apples. The apples were either treated with SmartFresh^{TM} at 10,000 ppb or not for 14 hours at 20°C before storage. The apples were then stored in either air or CA (2.5% O_2 plus 2.0% CO_2) for 16 weeks at 0°C. The apples were then stored for 6 weeks at 2°C in either air or CA (2.5% O_2 plus 2.0% CO_2) to simulate sea-freight conditions plus 6 days at 20°C to simulate marketing.

SmartFresh^{TM} concentration (ppb = parts per billion)	Total soluble solids (°Brix)		
	Land based to Sea-freight atmosphere		
	Air to air	CA to air	CA to CA
0 ppb	14.0	14.2	14.1
10,000 ppb	14.5	14.6	14.3
LSD (P=0.05)[1]	0.2[2]		
	0.2[3]		
	0.3[4]		

[1] Least significant difference of the means (5% level).
[2] Comparing down the air to air columns.
[3.] Comparing down the CA to CA columns.
[4.] For all other comparisons.

Table 25. Ground colour of Pink Lady apples. The apples were either treated with SmartFresh™ at 10,000 ppb or not for 14 hours at 20°C before storage. The apples then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C, followed by 6 weeks at 2°C to simulate sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Ground colour (hue angle = h°)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
0 ppb	100.1	104.8
10,000 ppb	102.8	104.2
LSD (P=0.05)[1]	1.4[2]	
	2.9[3]	
	2.3[4]	

[1] Least significant difference of the means (5% level).
[2] Comparing down the air columns.
[3.] Comparing down the CA columns.
[4.] For all other comparisons.

Table 26. Ground colour of Pink Lady apples. The apples were either treated with SmartFresh™ at 10,000 ppb for 14 hours at 20°C before storage. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C. The apples were then retreated or not with 1-MCP at 1,000 ppb for 18 hours at 4°C (pre-shipment treatment), followed by 6 weeks at 2°C simulated sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

Pre-shipment SmartFresh™ treatment	Ground colour (hue angle = h°)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
Pre-ship SmartFresh™ 0 ppb	101.9	104.5
Pre-ship SmartFresh™ 1000 ppb	101.1	-
LSD (P=0.05)[1]	1.4[2]	
	1.8[3]	

[1] Least significant difference of the means (5% level).
[2] Comparing down the air columns.
[3.] For all other comparisons.

Table 27. Ground colour of Pink Lady apples. The apples were either treated with SmartFresh™ at 10,000 ppb or not for 14 hours at 20°C before storage. The apples were then stored in either air or CA (2.5% O_2 plus 2.0% CO_2) for 16 weeks at 0°C. The apples were then stored for 6 weeks at 2°C in either air or CA (2.5% O_2 plus 2.0% CO_2) to simulate sea-freight conditions plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Ground colour (hue angle = h°)		
	Land based to Sea-freight atmosphere		
	Air to air	CA to air	CA to CA
0 ppb	99.5	100.7	104.8
10,000 ppb	101.2	104.3	104.2
LSD (P=0.05)[1]	2.0[2]		
	2.9[3]		
	2.5[4]		

[1] Least significant difference of the means (5% level).
[2] Comparing down the air to air columns.
[3.] Comparing down the CA to CA columns.
[4.] For all other comparisons

Experiment 2 (Part 3). SmartFresh™ Pink Lady simulated shipment trial. Effect of treatment before and after storage.

Table 28. Firmness of Pink Lady apples. The apples were either treated with SmartFresh™ at 1,000 ppb or not for 14 hours at 20°C before storage. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C, followed by 6 weeks at 2°C to simulate sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Firmness (kgf)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
0 ppb	6.4	7.0
1000 ppb	7.6	7.6
LSD (P=0.05)[1]	0.2[2]	
	0.3[3]	
	0.3[4]	

[1] Least significant difference of the means (5% level).
[2] Comparing down the air columns.
[3.] Comparing down the CA columns.
[4.] For all other comparisons

Table 29. Firmness of Pink Lady apples. The apples were either treated with SmartFresh™ at 1,000 ppb for 14 hours at 20°C before storage. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C. The apples were then retreated or not with 1-MCP at 1,000 ppb for 18 hours at 4°C (pre-shipment treatment), followed by 6 weeks at 2°C simulated sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

Pre-shipment SmartFresh™ treatment	Firmness (kgf)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
Pre-ship SmartFresh™ 0 ppb	7.0	7.3
Pre-ship SmartFresh™ 1000 ppb	7.1	-[2]
LSD (P=0.05)[1]	0.2	

[1] Least significant difference of the means (5% level).
[2.] No data available.

Table 30. Firmness of Pink Lady apples. The apples were either treated with SmartFresh™ at 1,000 ppb or not for 14 hours at 20°C before storage. The apples were then either stored in air or CA (2.5% O_2 plus 2.0% CO_2) for 16 weeks at 0°C. The apples were then stored for 6 weeks at 2°C in either air or CA (2.5% O_2 plus 2.0% CO_2) to simulate sea-freight conditions plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Firmness (kgf)		
	Storage to Sea-freight atmosphere		
	Air to air	CA to air	CA to CA
0 ppb	6.1	6.8	7.0
1000 ppb	7.6	7.6	7.6
LSD (P=0.05)[1]	0.2[2]		
	0.3[3]		
	0.3[4]		

[1] Least significant difference of the means (5% level).
[2] Comparing down the air to air columns.
[3.] Comparing down the CA to CA columns.
[4.] For all other comparisons

Table 31. Total soluble solids content of Pink Lady apples. The apples were either treated with SmartFresh™ at 1,000 ppb or not for 14 hours at 20°C before storage. The apples were stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C, followed by 6 weeks at 2°C to simulate sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Total soluble solids (°Brix)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
0 ppb	14.0	14.3
1000 ppb	14.3	14.4
LSD (P=0.05)[1]	0.2[2]	
	0.5[3]	
	0.4[4]	

[1] Least significant difference of the means (5% level).
[2] Comparing down the air columns.
[3.] Comparing down the CA columns.
[4.] For all other comparisons

Table 32. Total soluble solids content of Pink Lady apples. The apples were either treated with SmartFresh™ at 1,000 ppb for 14 hours at 20°C before storage. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C. The apples were then retreated or not with 1-MCP at 1,000 ppb for 18 hours at 4°C (pre-shipment treatment), followed by 6 weeks at 2°C simulated sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

Pre-shipment SmartFresh™ treatment	Total soluble solids (°Brix)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
Pre-ship SmartFresh™ 0 ppb	14.1	14.3
Pre-ship SmartFresh™ 1000 ppb	14.2	-[2]
LSD (P=0.05)[1]	0.2[3]	
	0.3[4]	

[1] Least significant difference of the means (5% level).
[2.] No data available.
[3] Comparing down the air columns.
[4.] For all other comparisons

Table 33. Total soluble solids content of Pink Lady apples. The apples were either treated with SmartFresh™ at 1,000 ppb or not for 14 hours at 20°C before storage. The apples were then stored in either air or CA (2.5% O_2 plus 2.0% CO_2) for 16 weeks at 0°C. Then the apples were stored for 6 weeks at 2°C in either air or CA (2.5% O_2 plus 2.0% CO_2) to simulate sea-freight conditions plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Total soluble solids (°Brix)		
	Storage to Sea-freight atmosphere		
	Air to air	CA to air	CA to CA
0 ppb	13.8	14.1	14.3
1000 ppb	14.2	14.4	14.4
LSD (P=0.05)[1]	0.3[2]		
	0.5[3]		
	0.4[4]		

[1] Least significant difference of the means (5% level).
[2] Comparing down the air to air columns.
[3] Comparing down the CA to CA columns.
[4] For all other comparisons

Table 34. Ground colour of Pink Lady apples. The apples were either treated with SmartFresh™ at 1,000 ppb or not for 14 hours at 20°C before storage. The apples were stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C, followed by 6 weeks at 2°C to simulate sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Ground colour (hue angle = h°)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
0 ppb	98.6	100.7
1000 ppb	99.9	102.8
LSD (P=0.05)[1]	1.0[2]	
	2.1[3]	
	1.6[4]	

[1] Least significant difference of the means (5% level).
[2] Comparing down the air columns.
[3] Comparing down the CA columns.
[4] For all other comparisons

Table 35. Ground colour of Pink Lady apples. The apples were either treated with SmartFresh™ at 1,000 ppb for 14 hours at 20°C before storage. The apples were then stored in CA (2.5% O_2 : 2.0% CO_2) for 16 weeks storage at 0°C. The apples were then retreated or not with 1-MCP at 1,000 ppb for 18 hours at 4°C (pre-shipment treatment), followed by 6 weeks at 2°C simulated sea-freight in either air or CA (2.5% O_2 : 2.0% CO_2) plus 6 days at 20°C to simulate marketing.

Pre-shipment SmartFresh™ treatment	Ground colour (hue angle = h°)	
	Sea-freight atmosphere	
	Air	Controlled atmosphere
Pre-ship SmartFresh™ 0 ppb	99.4	101.7
Pre-ship SmartFresh™ 1000 ppb	99.1	-[2]
LSD (P=0.05)[1]	1.0[3]	
	1.3[4]	

[1] Least significant difference of the means (5% level).
[2.] No data available.
[3.] Comparing down the air columns.
[4.] For all other comparisons

Table 36. Ground colour of Pink Lady apples. The apples were either treated with SmartFresh™ at 1,000 ppb or not for 14 hours at 20°C before storage. The apples were then stored in either air or CA (2.5% O_2 plus 2.0% CO_2) for 16 weeks at 0°C. The apples were then stored for 6 weeks at 2°C in either air or CA (2.5% O_2 plus 2.0% CO_2) to simulate sea-freight conditions plus 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Ground colour (hue angle = h°)		
	Storage to Sea-freight atmosphere		
	Air to air	CA to air	CA to CA
0 ppb	97.1	100.1	100.7
1000 ppb	99.4	100.4	102.8
LSD (P=0.05)[1]	1.5[2]		
	2.1[3]		
	1.8[4]		

[1] Least significant difference of the means (5% level).
[2] Comparing down the air to air columns.
[3.] Comparing down the CA to CA columns.
[4] For all other comparisons

Experiment 3. SmartFresh™ Pink Lady commercial shipment trial. Effect of treatment and growing locality.

Table 37. Firmness of Pink Lady apples. Apples were harvested from 6 growers properties around Australia and treated with SmartFresh™ at 1,000 ppb or not for 14 hours at 20°C before storage. The apples were stored in CA (2.5% O_2 : 2.0% CO_2) for 15 weeks at 0°C, followed by 6 days at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Firmness (kgf)					
	Grower 4 Goulburn valley	Grower 5 SA[2]	Grower 6 SA	Grower 7 Goulburn valley	Grower 8 Tas[3]	Grower 9 WA[4]
0 ppb	7.5	7.7	7.4	7.1	7.6	6.4
1000 ppb	8.3	8.3	8.0	8.3	8.0	6.3
LSD[1] (*P*=0.05)	0.3	0.4	0.4	0.5	0.3	0.8

[1] Least significant difference of the means (5% level).
[2.] SA = South Australia [3.] Tas = Tasmania [4.] WA = Western Australia.

Table 38. Firmness of Pink Lady apples. Apples were harvested from 6 growers properties around Australia and treated with SmartFresh™ at 1,000 ppb or not for 14 hours at 20°C before storage. The apples were stored in CA (2.5% O_2 : 2.0% CO_2) for 18 weeks at 0°C, followed by 6 weeks actual sea-freight in air to the UK plus 1 day at 20°C to simulate marketing.

SmartFresh™ concentration (ppb = parts per billion)	Firmness (kgf)					
	Grower 4 Goulburn valley	Grower 5 SA[2]	Grower 6 SA	Grower 7 Goulburn valley	Grower 8 Tas[3]	Grower 9 WA[4]
0 ppb	7.0	7.3	7.3	6.6	6.5	-
1000 ppb	7.9	7.9	7.8	7.6	7.8	-
LSD[1] (*P*=0.05)	0.2	0.2	0.4	0.1	0.9	-

[1] Least significant difference of the means (5% level).
[2.] SA = South Australia [3.] Tas = Tasmania[4.] WA = Western Australia fruit was not sent to the UK because the pre-shipment assessments showed it did not meet export standard (see Table 37).

5.3 Simulated export trial: Effect of SmartFresh^{TM} on Pink Lady apple firmness

INTRODUCTION

In 2001, 2002 and 2003 fruit was harvested from 2 orchards in the Goulburn Valley and treated with SmartFresh^{TM} and after 6 months controlled atmosphere storage the fruit treated and not treated with SmartFresh^{TM} were shipped to the UK where the firmness of the fruit was assessed.

5.3.1 EXPERIMENTAL OBJECTIVES

Determine the effects of SmartFresh^{TM} on Pink Lady apple firmness after air and controlled atmosphere storage followed by simulated shipping to the UK at optimum 0°C or poor carriage temperature of 4°C.

5.3.2 MATERIALS AND METHODS

Season 2001
Pink Lady apples were harvested from 2 orchards (orchard 2 and orchard 5) in the Goulburn Valley on 26thApril, 2001 (commercial harvest). The fruit was stored overnight in a commercial cool-room. On arrival at DPI, Knoxfield, the fruit was placed at 4^{o}C. On the 2nd May the fruit was treated with SmartFresh^{TM} at 625 ppb for 14 hours at 20^{o}C. The 0 ppb control treatments were stored in chambers without SmartFresh^{TM} and were removed from the SmartFresh^{TM} treatment room first and placed in the 0°C cold store followed by the SmartFresh^{TM} treated fruit.

Non-SmartFresh^{TM} (control) and SmartFresh^{TM} treated fruit were stored in separate replicated controlled atmosphere CA chambers (2.5% O_2 plus 2% CO_2). Air stored fruit were held in a perforated plastic liner placed on top of the CA chambers. CA commenced on the 4th May. After 12 weeks in air or 18 weeks in CA the fruit were transferred to either 0^{o}C or 4^{o}C for 6 weeks to simulated shipping to the UK at optimal or sub-optimal shipping temperatures plus 1 day at 20^{o}C to bring the fruit to room temperature. The fruit firmness was measured using a hand held penetrometer with a hand held 11 mm plunger.

Season 2002
Pink Lady apples were harvested from 2 orchards (orchard 1 and orchard 4) in the Goulburn Valley on 19thApril, 2003 (commercial harvest). On the 19th April the fruit was treated with SmartFresh^{TM} as described for the 2001 harvest except that the treatment was for 24 hours at 20°C. CA commenced on the 23rd April. Storage and simulated shipping were the same as described for the 2001 harvest.

Season 2003
Pink Lady apples were harvested from 2 orchards (orchard 1 and orchard 5) in the Goulburn Valley on 10thApril, 2003 (commercial harvest). On the 11th April the fruit was treated with SmartFresh^{TM} as described for the 2001 harvest except that the treatment was for 24 hours at 12°C. CA commenced on the 13th April. Storage and simulated shipping were the same as described for the 2001 harvest.

Experimental design and statistical analysis

Design:

2 SmartFresh™ treatments x 5 field blocks x 12 fruit per block.

Treatments: SmartFresh™ at 0 ppb and 625 ppb (parts per billion)

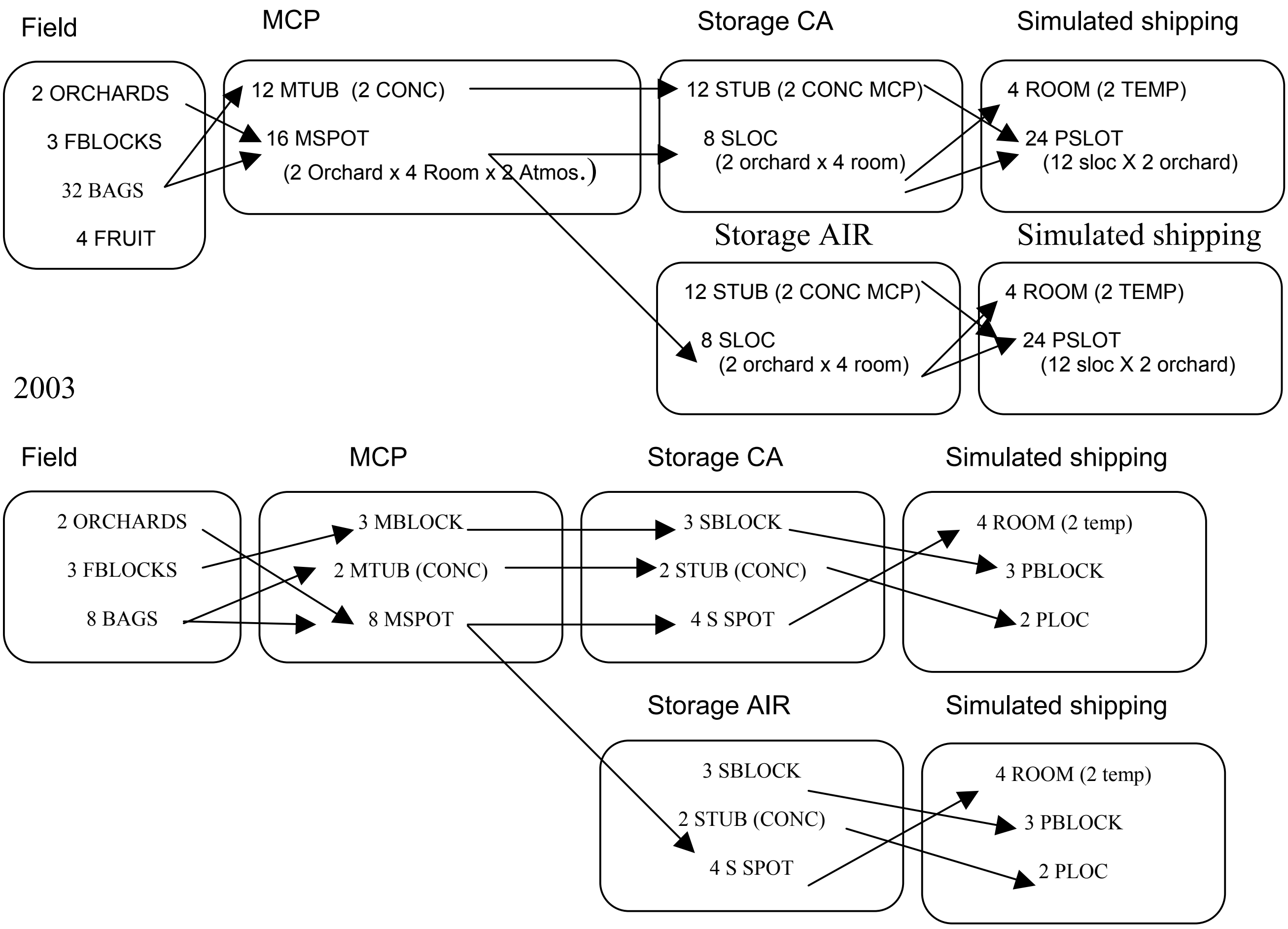
Treatments:

SmartFresh™ concentrations:	0 ppb and 625 ppb (parts per billion)
Storage time:	3 or 6 months
Atmosphere:	Air or CA
Shipping temperature:	0^{o}C and 4^{o}C

Statistical Analysis:

Figure 1. Diagram showing the four phases of the experimental design: Field, MCP, storage and shipping:

2002



Letter codes were used to differentiate the phases for analysis.
F = field (example FBLOCK = field block)
M = 1-MCP (example MBLOCK = 1-MCP treatment chamber block)
S = storage (example SBLOCK = Storage block at DPI)

5.3.3 RESULTS

Storage experiments in 2001 to 2003

Air storage experiment

In all years, the flesh of Pink Lady apples treated with SmartFresh^{TM} was significantly firmer than for untreated fruit after 3 months air storage followed by 6 weeks simulated shipping at 0°C or 4°C plus 1 day at 20°C (Tables 1, 2 and 3). This was true for the fruit from the two orchards used in the trials each year.

In 2001, the untreated fruit from both orchards held at 4°C simulated shipping temperature were significantly softer than fruit held at 0°C (Table 1)*. There was no significant effect of the simulated shipping temperature on SmartFresh^{TM} treated fruit from orchard 2. However, the fruit stored at 4°C from orchard 5 were significantly softer than fruit stored at 0°C whether they were treated with SmartFresh^{TM} or not.

In 2002 and 2003 the firmness of treated and untreated fruit from both was not significantly affected by the elevated simulated shipping temperature (Tables 2 and 3)

Controlled atmosphere storage experiment

Pink Lady apples treated with SmartFresh^{TM} were significantly firmer than untreated fruit after 6 months controlled atmosphere (CA) storage followed by 6 weeks simulated shipping at 0°C or 4°C plus 1 day at 20°C every year (Tables 4, 5 and 6). The exception was in 2001 when there was no significant difference in the firmness of treated and untreated of orchard 5 fruit held continuously at 0°C (Table 3). There was no significant effect of the simulated shipping temperature on firmness of treated or untreated fruit from all orchards in any of the years studied.

* All tables referenced are to be found within the current chapter.

5.3.4 TABLES

Table 1. The effect of SmartFresh^{TM} on Pink Lady apple firmness after 12 weeks air storage in 2001, followed by 6 weeks at 0^{o}C or 4^{o}C to simulate good and poor shipping temperatures followed by 1 day at 20^{o}C to bring the fruit to room temperature.

SmartFresh^{TM} Concentration (parts per billion)	Orchard 2		Orchard 5	
	0^{o}C	4^{o}C	0^{o}C	4^{o}C
0 ppb	7.3	6.9	6.9	6.7
625 ppb	8.5	8.3	8.1	7.6
LSD ($P=0.05$)[1]	0.2[2]			
	0.6[3]			

[1] Least significant difference of the means (5% level)
[2] Comparing means across a row at the same level of SmartFresh^{TM}.
[3] For all other comparisons.

Table 2. The effect of SmartFresh^{TM} on Pink Lady apple firmness after 12 weeks air storage in 2002, followed by 6 weeks at 0^{o}C or 4^{o}C to simulate good and poor shipping temperatures followed by 1 day at 20^{o}C to bring the fruit to room temperature.

SmartFresh^{TM} Concentration (parts per billion)	Orchard 1		Orchard 4	
	0^{o}C	4^{o}C	0^{o}C	4^{o}C
0 ppb	7.2	7.0	6.5	6.2
625 ppb	9.3	9.4	7.9	8.1
LSD ($P=0.05$)[1]	0.3			

[1] Least significant difference of the means (5% level)

Table 3. The effect of SmartFresh^{TM} on Pink Lady apple firmness after 12 weeks air storage in 2003, followed by 6 weeks at 0^{o}C or 4^{o}C to simulate good and poor shipping temperatures followed by 1 day at 20^{o}C to bring the fruit to room temperature.

SmartFresh^{TM} Concentration (parts per billion)	Orchard 1		Orchard 5	
	0^{o}C	4^{o}C	0^{o}C	4^{o}C
0 ppb	6.9	6.8	6.0	5.7
625 ppb	8.3	8.3	7.6	7.4
LSD ($P=0.05$)[1]	0.4			

[1] Least significant difference of the means (5% level)

Table 4. The effect of SmartFresh^{TM} on Pink Lady apple firmness after 18 weeks CA storage in 2001, followed by 6 weeks at 0°C or 4°C to simulate good and poor shipping temperatures followed by 1 day at 20°C to bring the fruit to room temperature.

SmartFresh^{TM} Concentration (parts per billion)	Orchard 2		Orchard 5	
	0°C	4°C	0°C	4°C
0 ppb	7.8	7.8	7.5	7.3
625 ppb	8.2	8.2	7.6	7.7
LSD (*P=0.05*)[1]	0.3			

[1] Least significant difference of the means (5% level)

Table 5. The effect of SmartFresh^{TM} on Pink Lady apple firmness after 18 weeks CA storage in 2002, followed by 6 weeks at 0°C or 4°C to simulate good and poor shipping temperatures followed by 1 day at 20°C to bring the fruit to room temperature.

SmartFresh^{TM} Concentration (parts per billion)	Orchard 1		Orchard 4	
	0°C	4°C	0°C	4°C
0 ppb	7.8	7.6	7.2	7.2
625 ppb	9.5	9.4	8.2	8.3
LSD (*P=0.05*)[1]	0.4			

[1] LSD =Least significant difference of the means (5% level)

Table 4. The effect of SmartFresh^{TM} on Pink Lady apple firmness after 18 weeks CA storage in 2003, followed by 6 weeks at 0°C or 4°C to simulate good and poor shipping temperatures followed by 1 day at 20°C to bring the fruit to room temperature.

SmartFresh^{TM} Concentration (parts per billion)	Orchard 1		Orchard 5	
	0°C	4°C	0°C	4°C
0 ppb	7.6	7.6	7.1	6.9
625 ppb	8.2	8.2	7.4	7.6
LSD (*P=0.05*)[1]	0.3[2]			
	0.5[3]			

[1] Least significant difference of the means (5% level)
[2] Comparing means down a column at the same level of temperature.
[3] For all other comparisons.

5.4 Commercial export trial: Effect of SmartFresh^{TM} on Pink Lady apple firmness

INTRODUCTION

In 2002 and 2003 fruit was harvested from 12 orchards in the Goulburn Valley and treated with SmartFresh^{TM}. After 6 months controlled atmosphere storage the fruit treated and not treated with SmartFresh^{TM} were shipped to the UK where the firmness of the fruit was assessed. The UK standard for imported Pink Lady apples is for the fruit to have a firmness value greater than or equal to 7 kgf with a minimum acceptance of 10% at 6.0 to 6.9 kgf.

5.4.1 EXPERIMENTAL OBJECTIVES

Determine the effect of SmartFresh^{TM} on Pink Lady apple firmness after prolonged storage and shipment to the UK.

5.4.2 MATERIALS AND METHODS

Season 2002

Pink Lady apples were harvested from 12 orchards in the Goulburn Valley between 29/4/2002 and 1/5/2002 during the normal commercial harvest period. On arrival at DPI, Knoxfield, the fruit was held at 0^{o}C. The fruit was treated with SmartFresh^{TM} (3.3% active ingredient 1-MCP) on the 7th May for 24 hours at 20°C. A 2,000,000 ppb concentrate was prepared and a gas sample was withdrawn with a syringe and injected into the 150 litre treatment chamber to deliver 625 ppb. Each chamber had a small fish tank pump running during the treatment to provide some air movement, see Plate 1. The fruit was treated inside their storage and export cartons. The 0 ppb control treatments were placed in chambers without SmartFresh^{TM} and were removed from the SmartFresh^{TM} treatment room first and placed in the 0°C cold store followed by the 625 ppb treatments. Non-SmartFresh^{TM} (control) and SmartFresh^{TM} treated fruit were stored in one large controlled atmosphere storage tent (2.5% O_2 plus 2% CO_2). The CA storage commenced on the 8th May. On the 26th August, the experimental cartons of fruit were delivered to Shepparton for inclusion in a commercial shipment of Pink Lady apples, to Chingford Fruit Packers in the UK. The fruit firmness was measured on the 10th October, using an automated firmness measuring unit, a Guss Food Texture Analyser (FTA). Fruit was also assessed for the incidence of flesh browning.

Season 2003

Pink Lady apples were harvested from 12 orchards in the Goulburn Valley between 10/4/2003 to 15/4/2003 at optimum physiological maturity based on a starch index value of approximately 4.5 (Based on the Ctifl 10 point scale index). On arrival at DPI, Knoxfield, the fruit was held at 4^{o}C. On the 16th April the fruit was treated with SmartFresh^{TM} at 625 ppb, using the same method as described in 2002 for 24 hours at 12°C. The fruit were held in nylon netting bags during the treatment treatment and were stored in plastic crates. The CA storage commenced on the 18th May. On the 22nd

August the CA was terminated and the nylon bags of fruit were transferred to export cartons. On the 1st September the experimental cartons of fruit were transported via a refrigerated truck to Lenswood, South Australia for inclusion in a commercial shipment of Pink Lady apples, to Chingford Fruit Packers in the UK. The fruit were shipped in a MAXtend modified atmosphere shipping container. The fruit firmness was measured on the 20th October in the UK, using an automated firmness measuring unit, a Guss Food Texture Analyser (FTA) see Plate 2. Fruit was also assessed for the incidence of flesh browning.

Experimental design and statistical analysis

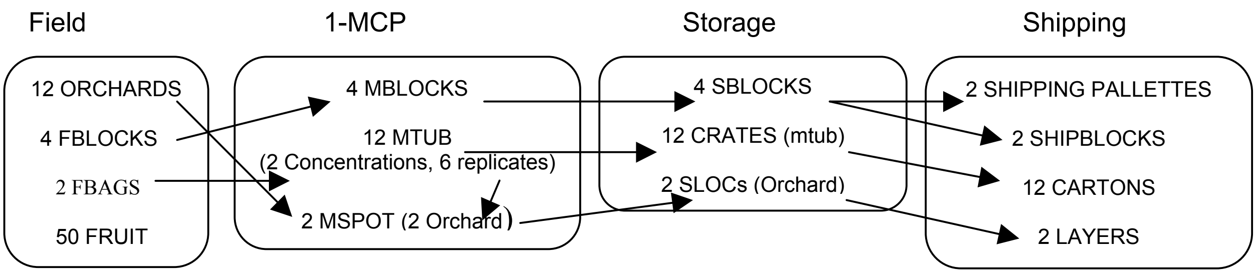
Design:

2 SmartFresh™ treatments x 4 field blocks x 50 fruit per block.

Treatments: SmartFresh™ at 0 ppb and 625 ppb (parts per billion)

Statistical Analysis:

Figure 1. Diagram showing the four phases of the experimental design: Field, MCP, storage and shipping:



Letter codes were used to differentiate the phases for analysis.
F = field (example FBLOCK = field block)
M = 1-MCP (example MTUB = 1-MCP tub)
S = Storage (example SBLOCK = Storage block at DPI)

Plate 1. Shows the typical SmartFresh^{TM} treatment chamber and experimental design lay-out used for all SmartFresh^{TM} experiment conducted in this project.

Plate 2. Food texture analyser used to measure Pink Lady apple firmness in the UK.

5.4.4 RESULTS

Season 2002

The fruit firmness was assessed in the UK on the 10th October. Fruit treated with SmartFresh™ were significantly firmer than fruit not treated with SmartFresh™ for all orchards (Figure 1). Orchard 8 fruit treated with SmartFreshTM had the smallest loss in fruit firmness which was 2.4 kgf compared to the not SmartFresh™ treated fruit. Orchard 11 fruit treated with SmartFresh™ had the greatest loss in fruit firmness which was 1.4 kgf compared to the not SmartFresh™ treated fruit.

Fruit softening during storage and shipping varied between the orchards. A comparison of the firmness outturn in the UK with the harvest firmness (Section 6.2.4: Table 5. Second harvest fruit 2002), indicates that overall, the firmness of fruit treated with SmartFresh™ decreased by approximately 0.25 kgf in storage and shipping to the UK compared to 2.5 kgf for fruit not treated with SmartFresh™.

The minimum percentage of fruit required by the importers Chingford Fruit Packers, is 90% of the fruit with a firmness greater than or equal to 7.0 kgf (Figure 2). Fruit treated with SmartFresh™ from all orchards met the standard. All fruit not treated with SmartFresh™ from all orchards failed to meet the standard. If the 10% tolerance is taken into account only two orchards with untreated fruit came close to meeting the import standard.

Season 2003

The fruit firmness was assessed in the UK on the 20th October. Fruit treated with SmartFresh™ were significantly firmer than fruit not treated with SmartFresh™ for all orchards (Figure 3). Orchard 4 fruit treated with SmartFreshTM had the smallest loss in fruit firmness of 0.9 kgf compared to untreated fruit. Orchard 5 fruit treated with SmartFresh™ had the greatest loss in fruit firmness of 0.4 kgf compared to the not SmartFresh™ treated fruit.

SmartFresh™ treated fruit were approximately 0.75 kgf firmer than fruit not treated with SmartFresh™. The firmness of fruit not treated with SmartFresh™ decreased by approximately 1.5 kgf, during storage and shipping to the UK (Section 6.2.4: Table 5. 1st harvest fruit 2003). The firmness of SmartFresh™ decreased by approximately 0.25 kgf as in 2002.

Fruit treated with SmartFresh™ from all orchards meet the minimum export firmness standard (Figure 4). However, fruit from only six orchards not treated with SmartFresh™ met the export standard.

The smaller difference in fruit firmness between treated and untreated SmartFresh™ fruit in 2003 compared to 2002 UK outturn can be attributed to firstly the fruit in 2003 being from the first harvest – optimum maturity compared to the commercial harvest date for fruit in 2002. Secondly, in 2003 the fruit was shipped to the UK in a MAXtend modified atmosphere shipping container and it is likely that the fruit not treated with SmartFresh™ may have benefited from the lower storage atmosphere in the container.

5.4.5 FIGURES

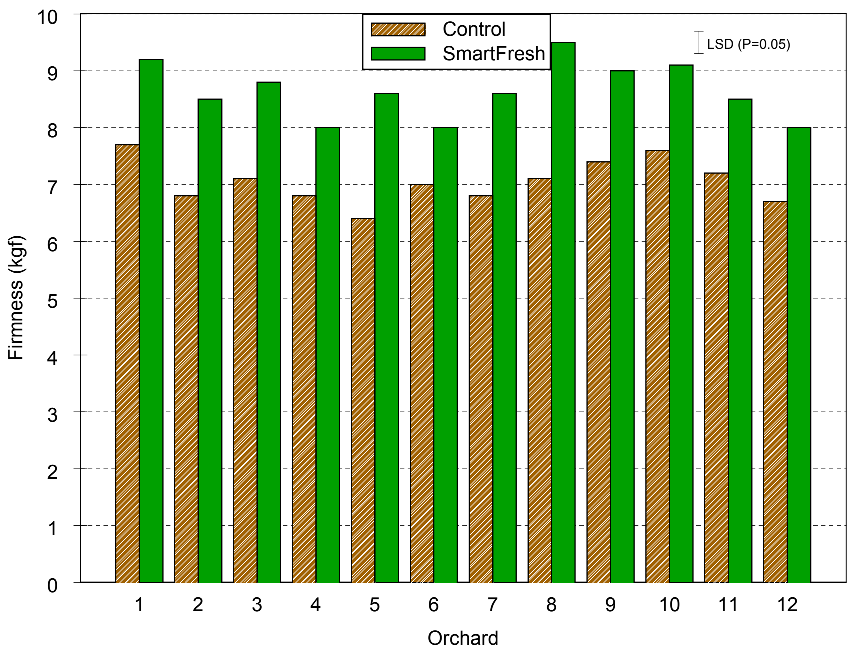


Figure1. Effect of SmartFresh™ on Pink Lady apple firmness assessed on the 10th October 2002, in the UK for fruit from twelve orchards in the Goulburn Valley.

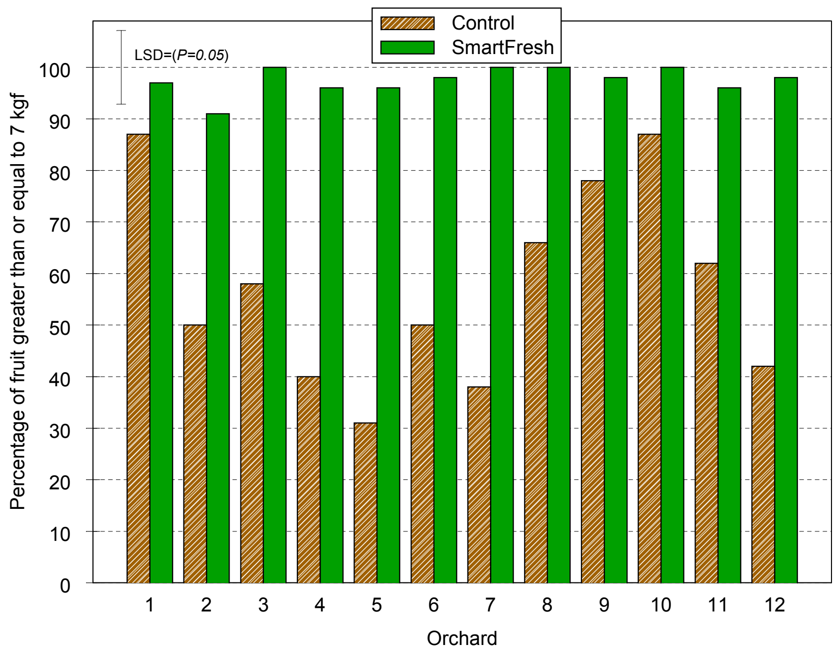


Figure2. The percentage of fruit greater than or equal to 7 kgf flesh firmness for Pink Lady apples treated with or without SmartFresh™ when assessed on the 10th October 2002, in the UK for fruit from twelve orchards in the Goulburn Valley.

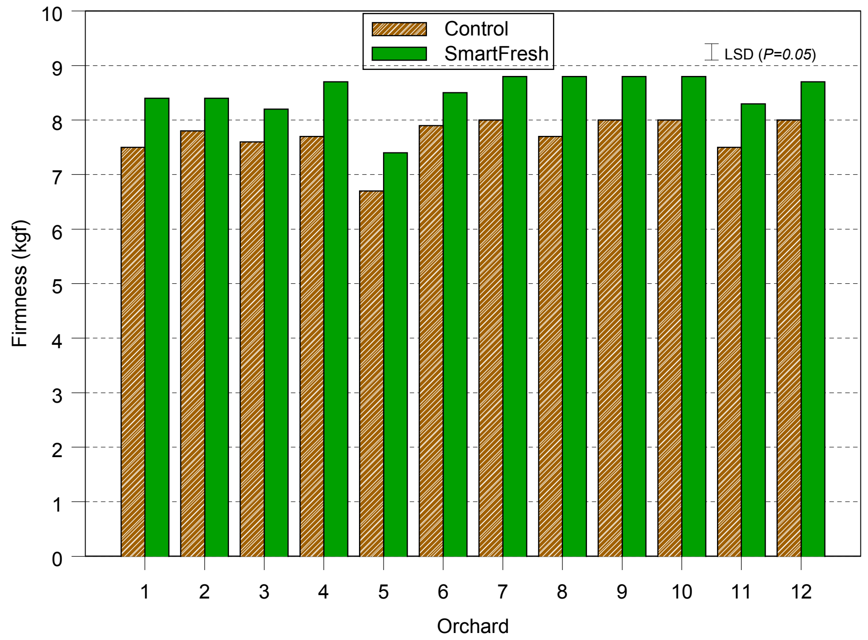


Figure 3. Effect of SmartFresh™ on Pink Lady apple firmness assessed on the 20th October 2003 in the UK for fruit from twelve orchards in the Goulburn Valley.

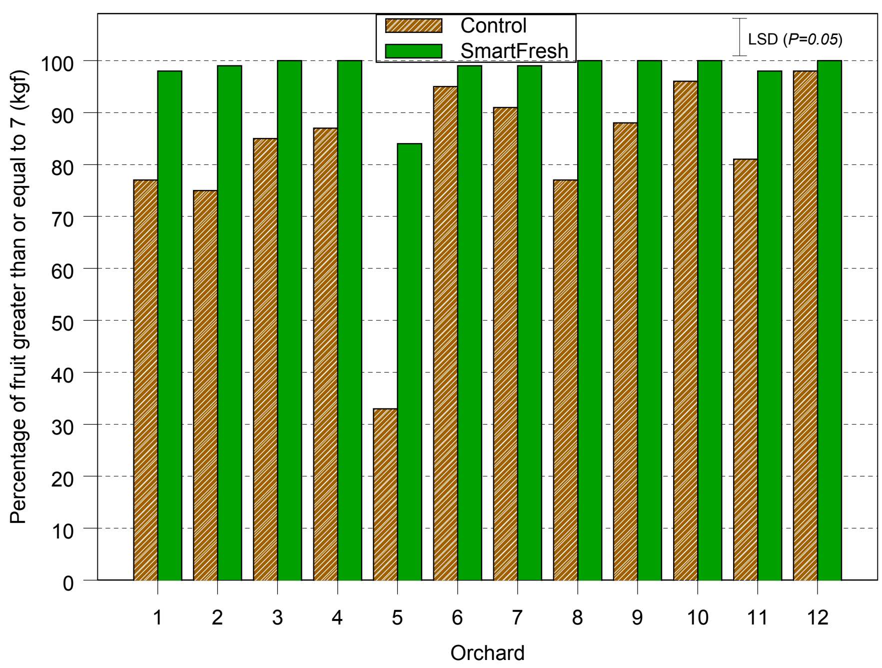


Figure 4. The percentage of fruit greater than or equal to 7 kgf flesh firmness for Pink Lady apples treated with or without SmartFresh™ when assessed on the 20th October 2003 in the UK for fruit from twelve orchards in the Goulburn Valley.

5.5 Effect of SmartFresh^{TM} on the storage quality of Tasmanian 'Jonagold' and 'Gala' apples for domestic and export markets.

Gordon S. Brown, Lisa J. Schimanski and David Jennings

INTRODUCTION

During the 2003 season the effect of SmartFresh^{TM} on the storage life and quality of 'Jonagold' and 'Gala' apples was investigated as a supplement to the Tracking Pink Lady apple firmness project. This project was incorporated into the Tracking Pink Lady apple firmness project at the request of Dan Ryan, Program Manager, Horticulture Australia Limited.

SmartFresh™ is a gas that is applied to apples after harvest to maintain fruit firmness during storage and subsequent marketing. Additionally, SmartFresh™ has the potential to replace DPA and prolong the storability of apples in controlled atmosphere storage. Aside from the benefits to fruit firmness, other benefits of SmartFresh™ have been noted to be the prevention of scald, reduction in spore inoculum, core flush, greasiness, mealiness and diffuse browning (Rohm and Haas / Agrofresh - publicity material distributed to Australian growers). 'Jonagold' and 'Gala' apples are two cultivars that suffer from soft fruit quality when they are marketed after extended storage and hence SmartFresh™ has potential to assist the Tasmanian apple industry in successfully marketing these cultivars.

5.5.1 EXPERIMENTAL OBJECTIVES

1. To demonstrate to growers the benefit of SmartFresh™ application on fruit quality and hence potential fruit sales and financial returns in order to encourage adoption of this technology.

2. To investigate the effect of the application of SmartFresh™ at label rates on 'Jonagold' and 'Gala' fruit quality after CA storage and simulated transport to distant markets.

5.5.2 MATERIALS AND METHODS

This project was developed as an industry development / demonstration project with the primary aim of demonstrating to growers the benefits of using SmartFresh™ in order to encourage adoption of this technology. The provider of the voluntary contribution assisted in the project design with the view of maximising industry exposure and confidence in the product. As a result this project was a industry demonstration activity and not a scientific investigation into the effect of SmartFresh™ on fruit quality. Hence, treatment replication, for statistical analysis purposes, was not incorporated into the project design.

Six boxes of 'Jonagold' and 6 boxes of 'Gala' were harvested from each of 2 growers. Due to the timing of the trial, the first harvest fruit were sampled from the 'Jonagold' apples, and the last harvest fruit were sampled from the 'Gala' apples. Within 24 hours of harvest 3 of the 6 boxes were placed in an airtight chamber and treated with

SmartFresh™ at 625 ppb for 24 hours. Fruit were then ventilated for 12 hours and returned to the growers for storage in their controlled atmosphere (CA) rooms. A box of SmartFresh™ treated fruit and an untreated control box were removed from these commercial CA rooms when they were opened for normal fruit withdrawal. The removal dates varied between 3 and 9 months after harvest, with a maximum of three withdrawal dates per grower (Table 1 and 2). At the time of fruit removal and various other times, as convenient, fruit were inspected by a range of different growers at individual meetings and grower field days and conferences. In addition three samples of twenty fruit from both boxes were removed. One of these samples was tested immediately for fruit quality and the second after simulated shipment in air to Asia (3-4 weeks) and after 7–10 days at 20 °C to test the shelf life and market quality of the fruit (sample 3).

Measurements and assessments

Fruit assessments included firmness, total soluble solids (TSS), background colour, (by scanning the equatorial peel and image analysis) greasiness (assessed on a 0-5 scale by feel) and visual assessment of internal and external disorders/rotting by counting the number of fruit affected.

5.5.3 RESULTS

Table 1. SmartFresh™ treatment effects on firmness of 'Gala' apples

	Grower 1			Grower 2		
	Date	Untreated Firmness (kgf)	SmartFresh Firmness (kgf)	Date	Untreated Firmness (kgf)	SmartFresh Firmness (kgf)
Harvest						
Harvest	28/03/2003	8.9	8.9	28/03/2003	7.9	7.9
1st Removal						
Post CA store	26/06/2003	7.2	8.6	27/08/2003	5.7	8.3
Post transport	18/07/2003	6.6	8.6	5/09/2003	5.7	9.3
Retail	25/07/2003	5.3	9.0	24/09/2003	5.3	8.1
2nd removal						
Post CA store	30/07/2003	6.2	8.7	Not Performed		
Post transport	29/08/2003	5.8	8.6	Not Performed		
Retail	5/09/2003	5.5	8.7	Not Performed		
3rd Removal						
Post CA store	19/09/2003	6.1	8.5	12/12/2003	4.7	8.3
Post transport	13/10/2003	6.0	8.5	7/01/2004	4.9	7.9
Retail	20/10/2003	5.4	9.0			
					Not marketable	Sound

The data was converted from newtons (N) to kilogram force (kgf) by the conversion factor 1kgf = 9.807 N.
Although the treated and untreated fruit were at the same firmness at harvest, the fruit not treated with SmartFresh™, were approximately 3kgf softer than the SmartFresh™ treated fruit after simulated retailing (Tables 1 and 2). This response was observed for both cultivars and at all removal dates including fruit stored in CA for only 3 months. While there appeared to be no effect of storage duration on fruit firmness after retail marketing a storage duration effect on the firmness of the fruit when it was removed from CA was observed with the early removal dates resulting in firmer fruit at the time of fruit grading and packing. These results demonstrate that fruit that has been CA stored for a short period are sound at the time of grading and packing but deteriorate rapidly during transport and marketing. This explains the market rejections of the fruit that commonly occurs especially with longer stored fruit.

SmartFresh™ treated fruit displayed a different pattern of fruit softening during storage, transport and retail marketing. For SmartFresh™ treated fruit softening did not occur such that after simulated retail marketing fruit were of a similar firmness to freshly harvested fruit. This was observed for all removal dates for CA storage periods of up to 8 months. Hence, with SmartFresh™ treatment, fruit is not anticipated to soften during transport and marketing such that fruit that is within firmness specification at the time of grading and packing will still be in specification at the destination market. This will dramatically reduce the number of market rejections and should allow for market expansion.

Table 2. SmartFresh™ treatment effects on firmness of 'Jonagold' apples

	Grower 1			Grower 2		
	Date	Untreated Firmness (kgf)	SmartFresh Firmness (kgf)	Date	Untreated Firmness (kgf)	SmartFresh Firmness (kgf)
Harvest						
Harvest	28/03/2003	8.2	8.2	28/03/2003	8.5	8.5
1st Removal						
Post CA store	26/06/2003	6.8	8.0	26/06/2003	7.9	8.7
Post transport	18/07/2003	6.1	7.9	18/07/2003	7.5	8.6
Retail	25/07/2003	5.3	8.6	25/07/2003	5.6	9.0
2nd removal						
Post CA store	30/07/2003	6.4	7.9	Not Performed		
Post transport	29/08/2003	5.7	7.8	Not Performed		
Retail	5/09/2003	5.5	7.8	Not Performed		
3rd Removal						
Post CA store	19/09/2003	5.6	8.1	13/10/2003	6.0	8.3
Post transport	13/10/2003	5.5	8.1	10/11/2003	6.0	8.7
Retail	20/10/2003	5.3	8.3	17/11/2003	5.6	8.8

Table 3. The effect of SmartFresh™ on the fruit quality of 'Gala' apples*

Harvest parameter	Harvest	Storage parameter	Post storage		Post transport		Post Retail	
			Untreated	SmartFresh	Untreated	SmartFresh	Untreated	SmartFresh
Weight (g)	162	Weight (g)	144	141	138	135	131	127
Firmness (kgf)	8.2	Firmness (kgf)	6.1	8.4	5.9	8.4	5.3	8.6
TSS (% sucrose)	12	TSS (% sucrose)	13	13	14	14	14	14
Starch (% black)	53	Greasy feel (% fruit)	0	0	2	0	3	0
Diameter (mm)	70	External condition	1	0	0	0	0	0
		Internal condition	0	0	0	0	0	0

* averaged across grower and removal date

Table 4. The effect of SmartFresh™ on the fruit quality of 'Jonagold' apples

Harvest parameter	Harvest	Storage parameter	Post storage		Post transport		Post Retail	
			Untreated	SmartFresh	Untreated	SmartFresh	Untreated	SmartFresh
Weight (g)	166	Weight (g)	170	171	162	161	155	152
Firmness (kgf)	8	Firmness (kgf)	6.2	8.0	5.9	8.1	5.3	8.3
TSS (% sucrose)	14	TSS (% sucrose)	13	14	14	15	15	15
Starch (% black)	28	Greasy feel (% fruit)	0	0	0	0	1	0
Diameter (mm)	71	External condition	0	0	0	0	0	0
		Internal condition	1	0	1	0	1	1

* averaged across grower and removal date

5.5.4 CONCLUSIONS

The treatment of both 'Jonagold' and 'Gala' apples from Tasmania with SmartFresh™ resulted in fruit that were well above the market specifications (6.8kg and 14% TSS, Brown et al. 2003) both at arrival in the market place and after retail purchase. It should be noted that these fruit were in CA storage for up to 9 months before marketing. Untreated fruit were only above market specifications if the CA storage duration was less than 3 months, and were not marketable if storage was greater than 3 months.

These results demonstrate the remarkable effect of SmartFresh™ on fruit storage life. As a result of these trials and various meetings with growers and marketers orders have been placed for the commercial treatment of Tasmanian apples for the 2004 season.

5.5.5 PRESENTATIONS TO GROWERS

a) Numerous growers were met on an individual basis at various times and the treated fruit presented for their consideration. As a result of these meeting several orders for treatment were placed after tasting the treated apples.
b) Data was presented at the APAL national conference and treated and untreated apples were on display. As a result of this activity the Tasmanian Apple and Pear Growers Association decided that all Tasmanian Jonagold apples should be treated with this material.
c) A seminar and apple samples were presented to the Young Tasmanian Growers Association in November 2003. The growers considered the apples of amazing quality considering the time of year. All were suitable for marketing despite having undergone simulated transport to Asia. The untreated fruit were not marketable.

5.5.6 RECOMMENDATIONS

- That as many CA store operators as possible be encouraged to use SmartFresh™ for the 2004 season.
- In 2004, follow up work is needed to track the firmness of commercial fruit treated with SmartFresh™ , through the domestic and export market chains. This will be occurring as part of the SmartFresh™ commercialisation activities.

5.5.7 ACKNOWLEDGEMENTS

Jane Turner, Rohm and Haas Pty Ltd, trading as Agrofresh, Horticulture Australia and collaborative growers Andrew Scott, Thomas Frankcomb and Ian and Andrew Smith.

5.5.8 REFERENCES

Brown G, Schimanski L. and Jennings D. (2003). Successful export marketing of large 'Jonagold' apples. Final Report, Horticulture Australia Project AP99031.

6. MATURITY

6.1 Maturity literature review

Fruit should be harvested when they are mature but unripe and they still have the capacity to ripen normally and develop a full flavour. Fruit picked prematurely are likely to be small, poorly coloured and will not develop full taste. Conversely, fruit that is picked too late soften and become mealy, are more susceptible to bruising, flesh browning and decay. There are a number of fruit indices that growers can use to help them decide when to harvest. Common maturity indices include measuring changes in flesh firmness, skin flesh colour, seed colour, total soluble solids, titratable acidity and starch hydrolysis.

Pink Lady is a late maturing cultivar. There are many good publications available which outline how and when these measurements should be taken (Little and Holmes, 2000, Chennell et al. 2002, Collins, 2002, MacKay et al. 1994). Therefore, detailed descriptions on maturity indice measurements will not be presented in this report.

Monitoring the maturity status of fruit, provides the grower with the capacity to manage the storability of harvested fruit through timely harvesting. Unfortunately, harvest season factors such as weather, labour, and varying stages of colour development generally make it unfeasible to get all the fruit at ideal maturity. In the Goulburn Valley, Victoria Pink Lady matures ready to pick around mid to late April, depending on the season. The optimum firmness for picking Pink Lady apples for long term storage is 8 to 9.5 kgf or 7 to 8 kgf for immediate marketing (MacKay et al. 1994)

Generally, starch accumulates in the fruit during the growing season and is hydrolysed to sugar in the later stages of maturation and development (Peirs et al. 2002). The quantity of starch in fruit is about 2% to 4% of fresh weight at commercial harvest and although it disappears in apples during storage its products maintain the fruit metabolism throughout cold storage and marketing (Little and Holmes 2000, p 38).

Light crops, crops from extended bloom periods, or crops with high nitrogen levels may differ markedly in maturity and subsequent storage potential. Each block should be evaluated separately for its maturity and storage potential (Penn State College, 2003). It is important to monitor maturity during and at the end of harvest to know the spread of maturity for the harvest period.

If late-picked fruit is placed in CA storage for spring or summer marketing, fruit condition problems may arise. Although the fruit may have good firmness directly out of CA storage, it softens rapidly, resulting in an undesirable product arriving on the retail shelf (Olsen and Kupferman, 1984).

Section 6.4 will present the results of the effects of maturity at harvest on Pink Lady apple firmness after storage and shipping.

6.2 Effect of harvest maturity on Pink Lady apple firmness.

INTRODUCTION

The maturity of the fruit at harvest should determine its ultimate market destination. Harvest maturity is based on maturity indices for starch, firmness, total soluble solids content, percentage blush and intensity, background colour and titratable acidity. In the Goulburn Valley some orchards have had problems colouring the fruit to meet the market specification for colour and this may have resulted in the fruit being over-mature in respect to the other maturity indices. Therefore, to establish if over-maturity was a major contributing factor to soft fruit outturns after storage, fruit were harvested at optimum maturity based on the starch index of approximately 4.5 and a later harvest at approximately 7.5 based on the Ctifl 10 point starch index).

6.2.1 EXPERIMENTAL OBJECTIVE

1. Determine the effect of harvest maturity on Pink Lady apple firmness.
2. Produce a 10-point starch index chart for Pink Lady apples.
3. Develop a limiting factor approach using existing harvest maturity indices to decide when to harvest.

6.2.2 MATERIALS AND METHODS

Season 2001

Pink Lady apples were harvested from six orchards in the Goulburn Valley. The trees were grown on mm106 rootstock. The tree ages were: orchard 1, 7 years; orchard 2, 7 years; orchard 3, 7 years; orchard 4, 8 years; orchard 5, 8 years and orchard 6, 5 years. The fruit was harvested at two maturities, optimum and late maturity based on the starch index, 10 point Ctifl starch chart (see Plate 1).

Colin Little monitored the harvest maturity up to and during harvest. The maturity indices measured by Colin Little were starch index using the 10 point Ctifl starch chart, firmness (kgf) using a hand held penetrometer, total soluble solids (^{o} Brix) using a hand held refractometer, red blush using the visual percentage of apple surface area showing some degree of redness and red intensity using a rating scale of 1 = pale bronzy red to 5 = full red colour. In addition, at each harvest, fifteen fruit were picked and assessed for firmness and starch by DPI, Knoxfield staff.

As deciding when to harvest is based on a combination of factors a limiting factor approach was developed to assist growers in the decision of when to harvest. The accepted optimum harvest standards for long-term storage are a starch score of 4.5 (Ctifl), firmness greater than 8 kgf, TSS greater than13.5 ^{o}Brix and 40 to 50% blush. Fruit sampled for maturity assessment is recorded and the percentage of fruit that meets the harvest standard is plotted against time. The harvest commences when all harvest indices meet 80% of the standard. The limiting factor is that parameter that holds off commencing the harvest.

Season 2002
Pink Lady apples were harvested from twelve orchards in the Goulburn Valley. The tree ages were: orchard 1, 8 years; orchard 2, 8 years; orchard 3, 8 years; orchard 4, 9 years; orchard 5, 9 years; orchard 6, 6 years; orchard 7, 7 years; orchard 8, 6 years; orchard 9, 7 years; orchard 10, 7 years; orchard 11, 9 years and orchard 12, 7 years. The fruit was harvested at two maturities, optimum and late maturity based on the 10 point Ctifl starch index. Maturity assessments were as described for season 2001.

Season 2003
Pink Lady apples were harvested from the same twelve orchards as in 2001 / 2002 in the Goulburn Valley. The fruit was harvested at two maturities, optimum and late maturity based on the 10 point starch starch index. Maturity assessments were as described for season 2001.

The 10 point Ctifl starch conversion chart is a stylised pictorial representation of starch clearance patterns for radial type fruit. Pink Lady apples have radial type starch patterns. As part of this project a 10-point starch clearance chart has been developed that uses actual Pink Lady apple photographs.

6.2.3 RESULTS

Harvest dates
In 2000 / 2001 the first harvest was on the 13th April and the second was on 26th April (Table 1)*. In 2001/2002 the first pick was 4 to 5 days later than in 2000/2001. The second pick was approximately 13 days after the first pick. In 2002 / the first pick for most orchards was 10th to 15th April. The second pick was 9 to 17 days later.

The growers participating in this project were asked to provide the actual harvest dates when they started harvesting from the same orchard block (Table 2). Most growers started picking close to the projects second pick in most years. The exceptions being orchards 1 and 3, which commenced picking close to, the projects first pick in 2000/2001.

Starch scores
The fruit was picked based on physiological maturity. That is, it was picked based on the starch scores. The Ctifl starch chart was used to record starch score (Plate 1). The aim was to pick the fruit at optimum physiological maturity based on A starch score of about 4.5 and the second harvest at commercial harvest with a Ctifl score of about 7.5.

In 2001, the Ctifl scores were close to the target with the exception being orchard 3 that had starch scores of 8.2 and 8.9 for the first and second picks (Table 3).

In 2002, most orchards were harvested close to the target scores. The exceptions being for orchard 6 and orchard 12 that had starch scores higher than anticipated being 7.2 and 7.4 at the first harvest. In the second pick, most orchards were harvested slightly early with an average starch score about 6.

* All tables referenced are to be found within the current chapter.

In 2003, most orchards were harvested close to the target scores for the first pick the exception being orchard 11 with a starch score of 6.9 for the first pick. In the second pick, most orchards had starch scores of about 8. The exceptions being orchards 7 and 8 with scores of 5 and 5.8 respectively.

The Ctifl starch chart is a stylised starch conversion chart for radial type apples. DPI, Knoxfield has prepared a starch clearance chart based on actual Pink Lady apple starch tests (Plate2).

Plate 3 shows three samples of iodine-stained Pink Lady apples taken from different orchards within this project. Iodine reacts with starch to form a dark blue / purple colour. Plate 3a best depicts what is generally conceived to be optimal starch patterns for long-term CA storage, Plate 3b medium-term CA storage and Plate 3c short-term CA storage.

Starch charts are a guide to storage potential because the more starch present at harvest means there is more potential energy left to maintain the fruits integrity during storage. The energy comes from the conversion of starch to sugars. Therefore, using the DPI starch chart it is recommended the fruit starch patterns for long term CA storage fall between 3 and 5, but it is preferable that the majority of the fruit falls within ratings 3 and 4 because the fruit has more starch. Up to, 20% of fruit with a rating of 5 would be acceptable.

Firmness

The aim was to be able to pick fruit with a firmness greater than 8 kgf for long term CA storage. Colin Little recommends that the fruit has an average fruit firmness of 8.0 to 8.6 kgf for long term CA storage, 7.5 to 8.0 for medium term CA storage and 7.0 to 7.6 kgf for short term CA storage.

In the 2001,2002 and 2003 harvests, the average fruit firmness at pick one was greater than 8 kgf (Table 4). The exceptions being orchard 3 in 2001 and orchard 5 in 2003. In 2001 and 2002 the average fruit firmness at pick 2 was also greater than 8 kgf. The exception being orchard 3 in 2001. In 2003 in the second pick only orchards 4, 7 and 8 had an average fruit firmness greater than 8 kgf

The average fruit firmness is a guide to storage potential. It is important when deciding the storage potential of the fruit to know the percentage of fruit that are greater than or equal to 8 kgf. not just the average fruit firmness. The aim would be to have at least 80% of the fruit tested with a firmness of 8kgf or greater. In 2001 at the first harvest only orchard 3 failed to meet this criterion (Table 5). However, by the second harvest only orchard 2 and 4 met the criterion. In the 2002 harvest all orchards met the criterion for both harvests. The exception was orchard 6 where only 50% of the fruit tested greater than 8 kgf. In the 2003 harvest only orchards 1,2,3,4,6,7,8,10 and 11 met the criterion at the first harvest and at the second harvest only orchard 4 met the criterion.

Fruit size

Fruit size was not measured for the 2001 harvest. In the 2002 harvest the average fruit size ranged from 75 mm to 78 mm diameter in all the orchards (Table 6). In the 2003 harvest the average fruit size ranged from 70 mm to 74 mm diameter from all orchards. The exception was orchard 5 where fruit averaged 68 mm.

Limiting factor principle

Orchardists and maturity testers tabulate the means for starch, firmness, total soluble solids, percentage red cover and red intensity to determine when to start harvesting Pink Lady apples for long-term CA storage (LTCA). Limiting factor approach requires that 80% of the fruit assessed meet the harvest maturity standard set to meet the market destination.

In 2001 it was proposed that orchardists should calculate the percentage of fruit that meets the criteria for long-term CA storage. For example if the Standards were set at: Starch 90% to 50%, firmness 8 to 9.5 kgf, TSS 13.5 °Brix, red colour intensity 4 (1= pale bronzy red and 5 = full clear red), red cover 40 to 50% then calculate the percentage of fruit that falls within the standard. Based on what was termed the 'limiting factor principle' when 80% of the test sample meet the harvest criteria fruit is ready to harvest. The harvest is limited by the factor not meeting the 80 % standard. Using Colin Little's maturity data for orchards 1 all the standards meet the 80% standard between the 16/4/2004 and the 21/4/2004 giving a 5 day picking window for LTCA (Fig.1a). Beyond the 21/4/2004 the starch and firmness levels have dropped below the standard. Orchard 4 fruit was never going to be suitable for LTCA (Fig. 1b). The fruit was limited by red colour development and by the time red colour meet the standard, firmness and starch levels were unacceptable for LTCA.

The importance of knowing the maturity of the fruit during and at the end of harvest is extremely important.

6.2 4 TABLES

Table 1. Harvest dates for the 1st pick (optimum physiological maturity) and 2nd pick (commercial pick) in 2001, 2002 and 2003 harvests, for the twelve orchards in the Goulburn Valley participating in the Tracking Pink Lady apple project.

Orchard	2001		2002		2003	
	1st pick	2nd pick	1st pick	2nd pick	1st pick	2nd pick
1	13 April	26 April	16 April	1 May	10 April	22 April
2	13 April	26 April	16 April	30 April	14 April	28 April
3	13 April	26 April	18 April	30 April	10 April	28 April
4	13 April	26 April	18 April	29 April	15 April	23 April
5	13 April	26 April	18 April	30 April	10 April	23 April
6	13 April	26 April	19 April	1 May	11 April	28 April
7	-	-	18 April	29 April	14 April	22 April
8	-	-	19 April	30 April	14 April	23 April
9	-	-	16 April	29 April	14 April	23 April
10	-	-	19 April	1 May	15 April	22 April
11	-	-	18 April	30 April	15 April	24 April
12	-	-	19 April	1 May	11 April	28 April

Table 2. Actual commercial harvest dates provided by the twelve growers in the Goulburn Valley as to when they started to pick the fruit from the same orchards being used for the Tracking Pink Lady apple project from twelve orchards in the Goulburn Valley.

Orchard	2001	2002	2003
1	10 April	15 April	15 April
2	29 April	2 May	1 May
3	12 April	1 May	28 April
4	26 April	28 April	2 May
5	20 April	30 April	2 May
6	26 April	30 April	22 April
7	-	24 April	22 April
8	-	22 April	22 April
9	-	29 April	29 April
10	-	2 May	15 April
11	-	29 April	21 April
12	-	2 May	28 April

Table 3. Average starch scores using the 10 point Ctifl starch chart for the 1st pick and 2nd pick in 2001, 2002 and 2003 harvests from twelve orchards in the Goulburn Valley

Orchard	Starch score (10 point Ctifl)					
	2001		2002		2003	
	1st pick	2nd pick	1st pick	2nd pick	1st pick	2nd pick
1	4.8	7.5	5.2	6.6	5.6	7.4
2	3.9	7.6	4.3	6.6	3.7	6.8
3	8.2	8.9	4.2	6.0	4.4	8.3
4	5.8	7.3	5.0	6.4	4.8	6.5
5	4.6	7.6	5.2	6.0	4.4	7.1
6	5.4	8.0	7.2	8.6	3.8	8.0
7	-	-	5.2	5.7	4.7	5.0
8	-	-	4.3	5.2	5.5	5.8
9	-	-	4.9	5.9	5.7	6.0
10	-	-	5.1	5.4	5.4	8.0
11	-	-	5.3	7.4	6.9	8.0
12	-	-	7.4	7.7	4.8	8.0

Table 4. Fruit firmness at harvest for 1st pick and 2nd pick in 2001, 2002 and 2003 harvests 2003 from twelve orchards in the Goulburn Valley

Orchard	Firmness (kgf)					
	2001		2002		2003	
	1st pick	2nd pick	1st pick	2nd pick	1st pick	2nd pick
1	9.1	8.3	10.2	9.2	8.1	7.6
2	9.4	9.0	10.3	8.8	8.8	7.8
3	7.9	7.5	10.1	8.6	8.3	7.2
4	9.9	9.3	9.4	8.1	8.5	8.4
5	8.8	8.1	10.0	8.8	7.4	6.9
6	9.4	8.2	8.6	8.2	8.2	7.7
7	-	-	9.8	9.0	8.6	8.2
8	-	-	10.7	8.8	8.8	8.1
9	-	-	10.2	8.9	8.1	7.9
10	-	-	10.1	9.2	9.1	7.9
11	-	-	9.9	8.8	8.7	7.7
12	-	-	9.4	8.9	8.1	7.8

Table 5. Percentage of fruit at harvest with a firmness greater than or equal to 8 kgf for the 1st pick and 2nd pick in 2001, 2002 and 2003 harvests from twelve orchards in the Goulburn Valley

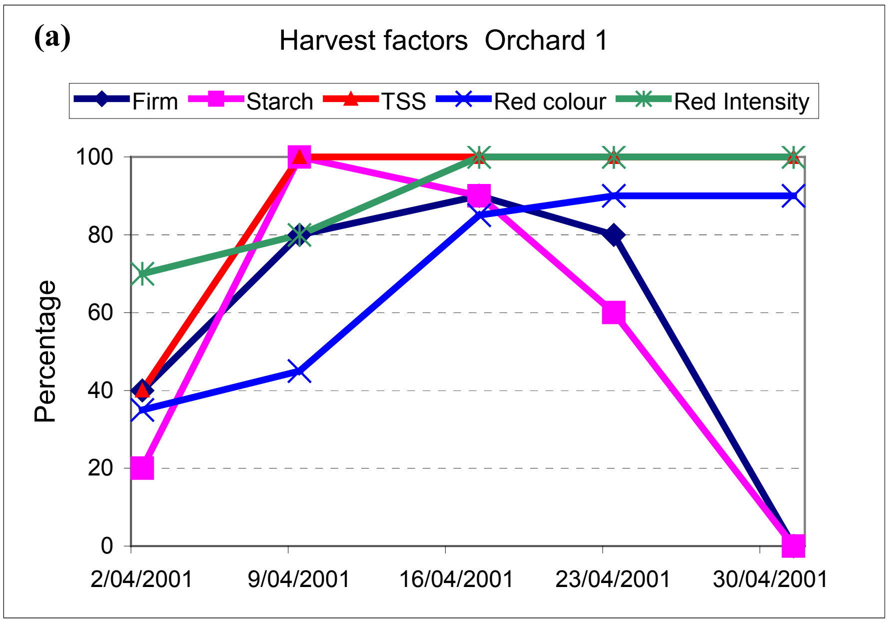
Orchard	Firmness (% > OR = 8kgf)					
	2001		2002		2003	
	1st pick	2nd pick	1st pick	2nd pick	1st pick	2nd pick
1	100	50	100	100	80	20
2	100	100	100	100	80	45
3	50	0	100	100	80	10
4	100	100	100	80	85	85
5	90	60	100	90	20	5
6	100	70	100	50	80	20
7	-	-	100	100	80	65
8	-	-	100	100	100	55
9	-	-	100	100	60	35
10	-	-	100	100	100	35
11	-	-	100	80	80	20
12	-	-	100	100	55	35

Table 7. Average fruit diameter (mm.) for 1st pick and 2nd pick in 2001, 2002 and 2003 harvests from twelve orchards in the Goulburn Valley

Orchard	Fruit diameter (mm)		
	2001	2002	2003
1	-	77	73
2	-	78	74
3	-	76	70
4	-	75	72
5	-	78	68
6	-	78	75
7	-	78	74
8	-	78	75
9	-	77	72
10	-	75	72
11	-	77	75
12	-	79	75

[1]Fruit size was not measured in 2001.

6.2.5 FIGURES



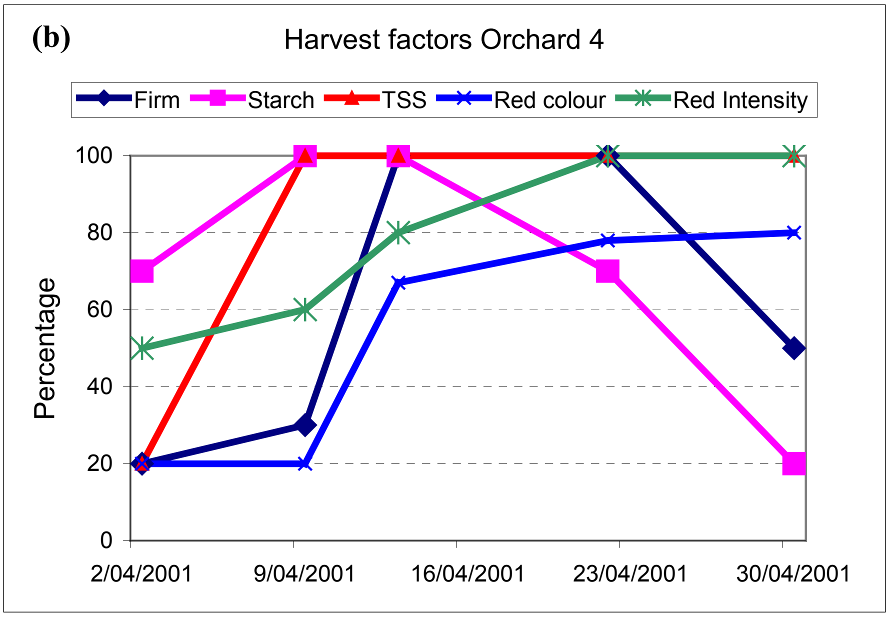


Figure 1. Harvest factors used to identify the harvest window for orchard 1 (a) and orchard 4 (b) based on the 'limiting factor principle'. Harvest factors were set at: Starch 90% to 50%, firmness 8 to 9.5 kgf, TSS 13.5 °Brix, red colour intensity 4, red cover 40 to 50% then the percentage of fruit that fell within the standards was calculated. The fruit was ready to harvest when all harvest factors were met by 80% of fruit in a test standard.

6.2.6 PLATES

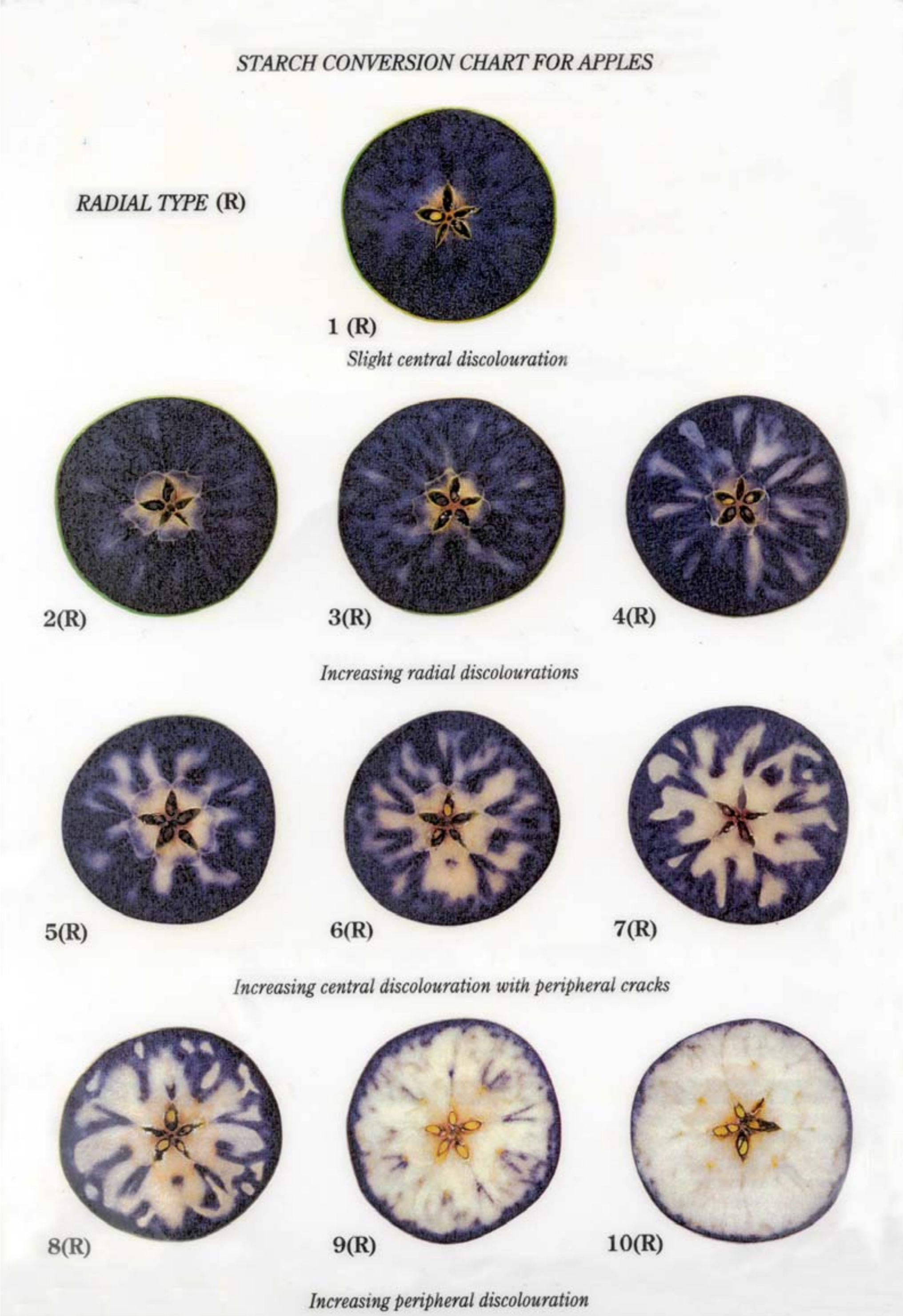


Plate 1. Ctifl 10 point starch-iodine rating scale used for scoring Pink Lady apple maturity at harvest.

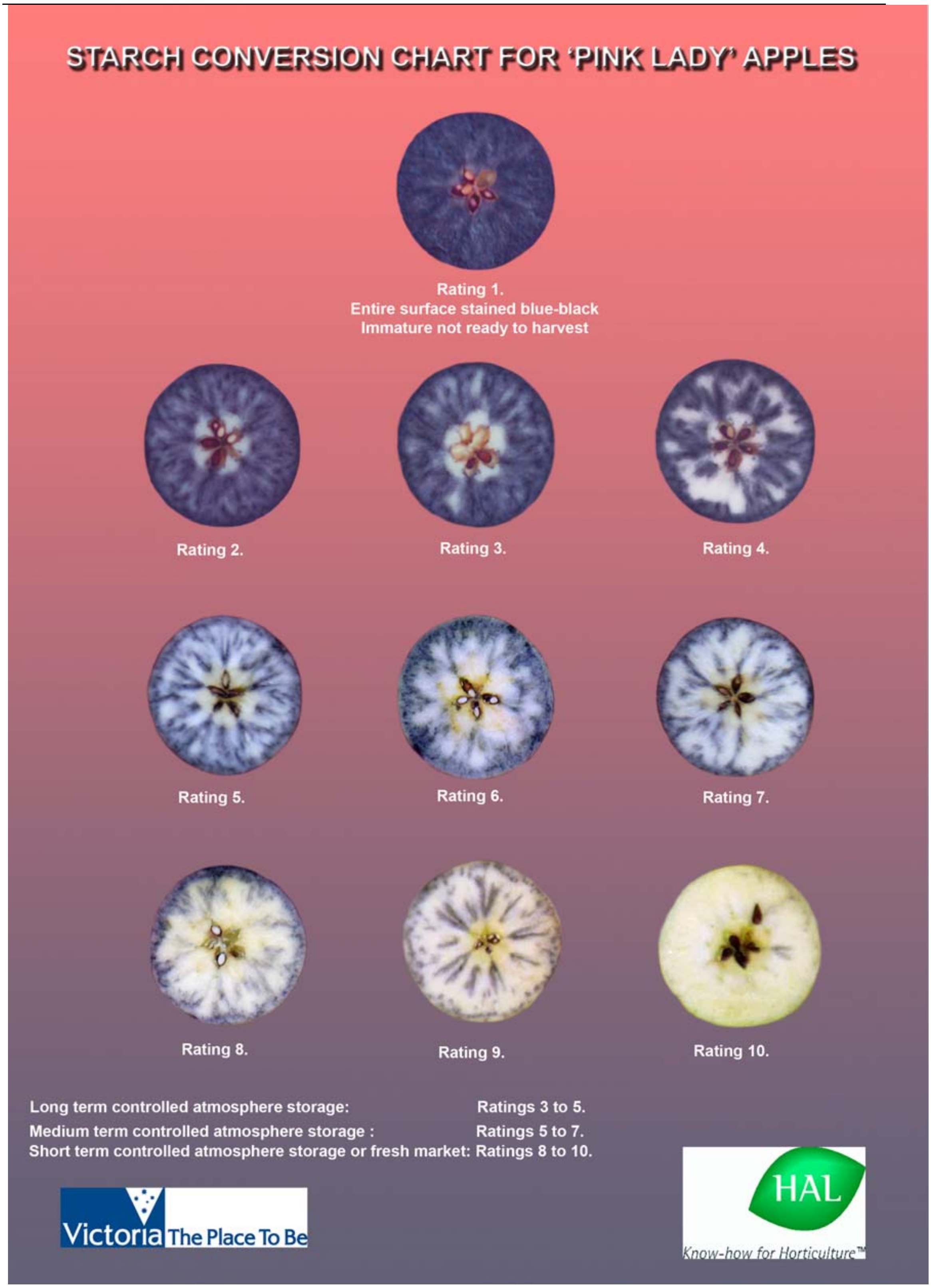


Plate 2. DPI, Knoxfield 10 point starch iodine rating scale for scoring Pink Lady apple maturity at harvest.

A

B

C

Plate 3. Different starch patterns for (A) long term CA storage, (B) medium term CA storage and (C) short term CA storage or immediate sale.

7. STORAGE AND SIMULATED SHIPPING

7.1 Storage and shipping literature review

Generally, apples soften faster in storage with advancing harvest date as a result of increasing maturity and ripeness. Consequently, firmness of fruit after removal from storage tends to be closely related to firmness at harvest (Lau, 1985, Knee and Smith, 1989).

Unlike pre-harvest softening, which is largely due to thinning of cell walls as the cells enlarge, post-harvest softening is mainly caused by the breakdown of the bonds between adjacent cells. The process enables cells to be separated more easily and slide against one another (Little and Holmes 2000, p.40).

In general, the treatment of fruit at harvest and during storage has a bigger impact on firmness of fruit than preclimacteric factors. The two key factors during storage are temperature and controlled atmosphere (CA) conditions (Harker et al. 2000).

Much of the variation in firmness between apples harvested on different harvest dates may be reduced during storage (Harker et al. 1997). Once harvested, firmness generally declines as ethylene production or internal ethylene concentration (IEC) increases (Yoshioka et al. 1995, Watkins et al. 2000).

Over the years, many techniques have been developed to regulate the physiological effects of ethylene. Controlled atmosphere is the standard for controlling postharvest ethylene production and respiration rate of apples. Many types of ethylene scrubbers have been developed; however, none are highly successful due to difficulty in reducing internal ethylene concentrations below physiologically active levels. Softening is reduced in CA if the ethylene level is maintained below IEC of 0.1 μl/L (Stow et al. 2000) and 1 μl/L (Liu, 1977), respectively. Johnston et al. (2001 a & 2002 a, b) found that the onset of rapid softening was consistently associated with an IEC that exceeded 1.5 μl/L.

High ethylene levels in the storage environment can initiate and stimulate fruit ripening (Beaudry et al. 1993). Pink Lady apples are classified as a climacteric fruit. In climacteric fruit the autocatalytic ethylene production initiates ripening processes; including flesh softening. Pink Lady apples are very high ethylene producers (Kupferman, 2002a). Therefore, where possible ethylene should be scrubbed during loading of the storage room for the first 10 days (Little and Holmes 2000, p 423). Internal ethylene levels need to be kept at 1 ppm or lower which is difficult to maintain. The CA room must be filled and sealed in a short period to prevent an ethylene concentration in the fruit of more than 0.5 ppm while temperatures are in the 4°C to 6°C range during initial cooling to 0°C (Little and Holmes 2000, p.457). Low levels of oxygen (1.5%) and low temperatures (0°C to 1°C) help to inhibit the effects of high ethylene levels (200 ppm to 400 ppm) in storage on fruit ripening (Little and Holmes 2000, p.456).

For high ethylene producing varieties such as Pink Lady and Gala pull-down time that is the number of days from fruit intake to when the oxygen has been reduced to less than 5%, is critical to the storage potential of the fruit (Chennell et al. 2002).

The preclimacteric state cannot be maintained in storage even with the best CA storage. Ripening can be delayed by CA but not prevented. (Little and Holmes 2000, p 42).

Despite 0°C being the optimum postharvest temperature for slowing loss of firmness it is difficult to maintain fruit at these optimum temperature through the entire postharvest handling chain (Johnston et al. 2000c). Royal Gala apples remain firmer when stored at 0°C than at 3°C for storage duration’s less than 50 days but there was no benefit of storage at 0°C compared to 3°C after 75 days (Harker et al. 2000). Apples soften about twice as fast at 4°C than at 0°C and about three times as fast at 15°C than at 4°C (Hardenburg et al. 1986). For most cultivars, firmness retention is improved when CA is established earlier, rather than later, after harvest (Dilley et al. 1989).

Temperature is the prime means of maintaining fruit quality during shipping. It is important to maintain optimum cool chain management. For Pink Lady apples and this should be between 0°C.

Pink Lady apples are predominantly exported from Australia in 12 meter (40 foot) integral containers, which take 4 to 5 weeks to reach the UK. Amos (1999), found fruit temperatures within a palletised stow of Pink Lady apples ranged from 0.5°C to 5°C in a 40 foot container shipped from Australia to the UK with an air delivery set point of 0°C.

In 1997 there were differences in market quality in the UK between early and late shipments of Pink Lady apples. Early exported fruit tended to be greasy and soft and these problems were attributed to over mature fruit that had been air stored for up to 5 weeks prior to shipping. Early picked fruit went straight into CA storage and formed the basis of later shipments. These fruit were of a higher market quality. However, although the majority of fruit being sent later in the year arrived in the UK in very good condition some shipments had fruit rejected. The purpose of the storage and shipping trials were to establish the interaction between harvest maturity, storage conditions (air, commercial CA or experimental CA) and poor temperature management in simulated shipping containers on Pink Lady apple quality. In addition, actual shipments of Pink Lady apples were sent to the UK and the outturn was assessed.

7.2 Experiment 1. Storage experiment

INTRODUCTION

Storage conditions will affect the firmness of apples after storage, after export and in the retail chain. In attempting to identify why fruit from some orchards outturns softer than that from others, we needed to establish if storage conditions are a major factor. Therefore, fruit harvested from the orchards were stored in commercial air storage in the Goulburn Valley and in experimental air and CA storage at DPI, Knoxfield.

7.2.1 EXPERIMENTAL OBJECTIVE

Determine the effect of storage conditions and maturity on Pink Lady apple firmness after storage.

7.2.2 MATERIALS AND METHODS

Season 2001

Pink Lady apples were harvested from 6 orchards in the Goulburn Valley at optimum and late harvest maturity (see Section 6.2.4 Table 1). At each orchard, the fruit from each experimental block of trees were pooled and then 15 fruit were selected at random and placed in plastic mesh bags. The fruit was held temporarily in a commercial cool store prior to transporting the fruit to DPI, Knoxfield. On arrival, the replicate storage bags were placed in either air or CA (2.5% O_2 plus 2% CO_2). Fruit firmness was measured after 12 weeks air storage or 24 weeks CA storage and 1 day at 20°C to bring the fruit to room temperature.

Five field replicate bags of 15 fruit, from each orchard were stored in a commercial cool room. After 12 weeks the fruit was transported to DPI, Knoxfield where the fruit was stored for 1 day at 20°C before fruit firmness was measured.

The participating growers provided the date when they started harvesting from the orchard containing the experimental block of trees (see Section 6.2.4 Table 2). The actual harvest dates were able to be matched very closely to the harvest dates used for DPI storage trials. The potential outturn for commercially harvested fruit was tabulated using the DPI CA storage data firmness results.

Season 2002

In 2002, the handling and storage conditions were as reported for 2001 except that there were 12 orchards. The CA fruit were stored for 26 weeks and the commercial air stored fruit were stored for 14 weeks

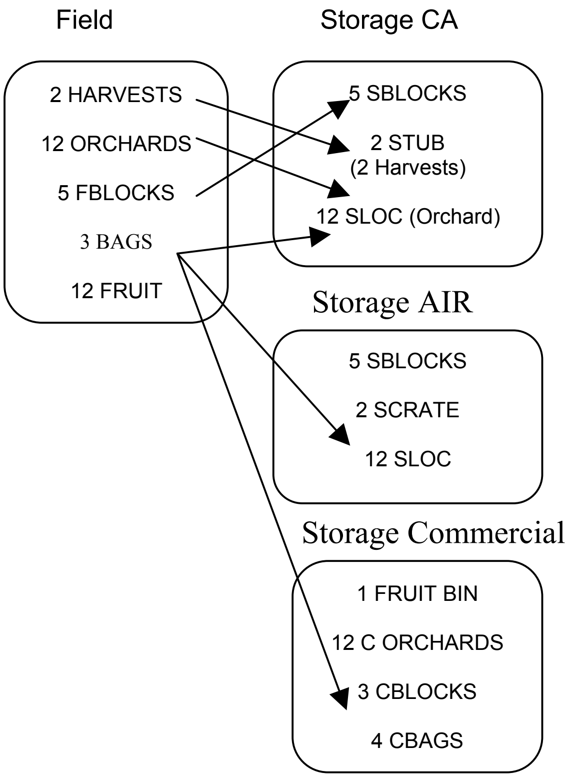
Season 2003

In 2003, the handling and storage conditions were as reported for 2001. Due to a fruit fly out-break in one region of the Goulburn Valley, fruit from orchards 6 and 12 were not included in the commercial storage trial.

Experimental design and statistical analysis

Figure 1. Diagram showing the two phases of the experimental design: Field and Storage. The CA and AIR storage treatments were identical except for their storage container (ie. CA tub or High RH bag)

In 2001 there were 6 orchards. In 2002, 2003, 12 orchards were used.



Letter codes were used to differentiate the phases for analysis.
F= field (example FBLOCK = field block)
S = storage (example SBLOCK = Storage block at DPI)
C = commercial (example CBLOCK = Commercial storage block)

Commercially stored fruit were not analysed as a two phase design because there was no block structure during the storage period. Therefore, only standard errors of the means were used for comparing the differences in fruit firmness between orchards.

7.2.3 RESULTS

Experimental Air storage
In the air storage experiment the fruit from harvest 1 and 2 were stored 3 months in air then 1 day at 20°C to warm the fruit to room temperature before the fruit firmness was measured.

Season 2001
In 2001, the flesh firmness of Pink Lady apples after storage from orchard 1was significantly firmer than all other orchards in the project with the exception of orchard 4. Orchard 1 fruit was 8.1 kgf compared to fruit from orchard 3 which had the softest fruit with a firmness of 7.0 kgf (Table 1)*.

Fruit from the second harvest were significantly softer for orchards 1,3 and 6 by approximately 0.3 kgf, but not for the other orchards.

In terms of export it is proposed that the fruit firmness needs to be greater than or equal to 7.5 kgf out of store to be considered suitable for shipping. If the fruit was harvested from the first pick orchards 1,2 and 4 fruit would have been suitable for export. For harvest two, fruit from orchards 1,2 and 4 would have still been suitable.

Season 2002
In 2002, the firmest fruit after storage, from pick 1, was from orchard 8 being 8.3 kgf and the softest fruit was from orchards 2 and 4. The firmness of fruit from orchard 8 was significantly greater than orchards 1, 2, 4, 6 and 12. The firmness of fruit from orchard 8 and 9 (8.1 kgf) second pick, was significantly greater than fruit from orchards 3,4,5,6,11 and 12. The softest fruit was from orchard 6 being 6.8 kgf (Table 2).

There was no significant effect of harvest date on fruit firmness for most orchards. Only orchard 3 and 11 had significantly softer fruit from the second harvest compared to the first.

In terms of export orchards 1,2,3,5,7,8,9,10 and 11 met the export standard for first pick fruit and for pick 2 orchards 1,2,5 7, 8,9 and 10 met the proposed standard of 7.5 kgf.

Season 2003
In 2003, the firmest fruit after storage from pick 1 was from orchards 9 and 12 being 6.8 kgf (Table3). The fruit from these orchards were significantly firmer than fruit from orchards 1,3 and 5. The softest fruit was from orchard 5 with a fruit firmness of 5.4 kgf. Fruit from orchard 5 from the second harvest were significantly softer than fruit from all others orchards at 5.5 kgf (Table 3).

There was no significant effect of the harvest date on outturn firmness except for orchards 1 and 6 where the fruit was significantly firmer from the second pick compared to the first pick. In general, there was no substantial difference in the fruit firmness between the two picks for most of the 12 orchards and this was reflected in the similar outturn turn firmness after 12 weeks air storage at DPI, Knoxfield. The increased firmness of fruit from orchards 1 and 6 for the second pick being firmer than first picked

* All tables referenced are to be found within the current chapter.

fruit after storage suggests it was picked more mature. This could have occurred as a result the first pick fruit being picked lower on the tree which matures faster than fruit higher in the tree from where the second pick fruit may have been sampled.

In terms of export no fruit from any orchard or maturity would have met the export proposed requirement of 7.5 kgf fruit firmness after storage.

Commercial air storage

Season 2001
In 2001, fruit from the first pick that was stored in a commercial coolroom were generally softer than fruit stored at DPI, Knoxfield conditions by approximately 0.3 kgf after storage (see Table 4 and Table 1).

Season 2002
In 2002, fruit from the second pick that was stored in a commercial coolroom were generally softer than fruit stored at DPI, Knoxfield by approximately 0.6 kgf after storage (Table 5). This varied between orchards and orchard 5 fruit was 0.7 kgf softer when stored at DPI, Knoxfield.

Season 2003
In 2003, fruit from the first pick that was stored in a commercial coolroom were over-all firmer than the fruit stored under the DPI storage conditions by approximately 0.5 kgf after storage (Table 6). This varied between orchards orchard 5 fruit was 1.2 kgf firmer when stored commercially. Fruit from the second harvest stored at DPI and commercially had very similar firmness outturns (Table 7).

Experimental controlled atmosphere (CA) storage

In the CA storage experiment fruit from harvest 1 and 2 were stored for 6 months in CA then 1 day at 20°C to warm the fruit to room temperature before the fruit firmness was measured.

Season 2001
In 2001, after CA storage orchard 4 had the firmest fruit being 8.3 kgf for the first pick and 8.0 for the second pick (Table 8). The softest fruit was from orchard 5, for harvest 1 and orchards 5 and 6 for harvest 2.

Fruit firmness for the first pick for all orchards, with the exception of orchards 5 met the proposed export criterion of 7.5 kgf. For pick 2, only orchards 1,2 and 8 met the export firmness criterion.

There was no significant effect of harvest date on the outturn firmness for orchards 1, 2, 4 and 5. Fruit from the second pick was significantly softer than first.pick fruit for orchards 3 and 6.

The firmness outturn for CA stored fruit after 6 months was very similar to the outturn firmness of air stored fruit after 3months storage.

Season 2002
In 2002, firmest fruit was from orchards 1,7 and 9 being 8.3 and the softest fruit was from orchard 12 being 7.3 kgf (Table 9).

Fruit firmness for the first pick for all orchards, with the exception of orchards 6 and 12 met the proposed export criterion of 7.5 kgf. For pick 2, only orchards 2,8,9 and10 met the export firmness criterion.

Fruit picked at the second harvest was significantly softer than the first pick fruit for all orchards. The exception being orchard 8.

Season 2003
In 2003, the firmest fruit was from orchard 7 being 8.1kgf and the softest fruit was from orchard 5 being 6.8 kgf (Table 10).

Fruit firmness for the first pick for all orchards, with the exception of orchards 5 met the proposed export criterion of 7.5 kgf. For pick 2, only orchards 4, 7, 8,9,10 and12 met the export firmness criterion.

7.2.4 TABLES

Table 1. Effect of maturity (1st harvest optimum physiological maturity) and 2nd harvest 'commercial' on the firmness of Pink Lady apples (kgf), in 2001. Fruit were from six orchards in the Goulburn Valley and assessment was after 12 weeks air storage at DPI, Knoxfield plus 1 day at 20^{o}C.

Orchard	Maturity	
	1	2
1	8.1	7.8
2	7.7	7.5
3	7.0	6.7
4	7.9	8.0
5	7.3	7.1
6	7.4	7.1
LSD (*P=0.05*)[1]	0.2	

[1] Least significant difference of the means (5% level).

Table 2. Effect of maturity (1st harvest optimum physiological maturity and 2nd harvest 'commercial') on the firmness of Pink Lady apples (kgf), in 2002. Fruit were from twelve orchards in the Goulburn Valley and assessment was after 12 weeks air storage at DPI, Knoxfield plus 1 day at 20^{o}C.

Orchard	Maturity	
	1	2
1	7.5	7.8
2	7.6	7.7
3	8.2	7.2
4	7.1	7.0
5	7.9	7.5
6	7.1	6.8
7	8.0	7.7
8	8.3	8.1
9	8.0	8.1
10	8.2	8.0
11	8.0	7.2
12	7.4	6.9
LSD (*P=0.05*)[1]	0.4	

[1] Least significant difference of the means (5% level).

Table 3. Effect of maturity (1st harvest optimum physiological maturity and 2nd harvest 'commercial') on the firmness of Pink Lady apples (kgf), in 2003 from twelve orchards in the Goulburn Valley and assessment was after 12 weeks air storage at DPI, Knoxfield plus 1 day at 20^{o}C.

Orchard	Maturity	
	1	2
1	6.3	6.8
2	6.6	6.7
3	6.3	6.4
4	6.4	6.6
5	5.4	5.5
6	6.4	7.0
7	6.5	6.5
8	6.7	6.9
9	6.8	7.1
10	6.7	7.0
11	6.6	7.0
12	6.8	7.0
LSD (*P=0.05*)[1]	0.4	

[1] Least significant difference of the means (5% level).

Table 4. Effect of maturity (1st harvest optimum physiological maturity) on the firmness of Pink Lady apples (kgf), in 2001. Fruit was from six orchards in the Goulburn Valley and assessment was after 12 weeks commercial air storage in a commercial cool store in the Goulburn Valley plus 1 day at 20^{o}C.

Orchard	Firmness (kgf) ± se[1]
1	7.8 ±0.06
2	7.3 ±0.06
3	6.7 ±0.06
4	7.9 ±0.08
5	7.5 ±0.08
6	7.0 ±0.05

[1] se = standard error of the mean

Table 5. Effect of maturity (2nd harvest 'commercial') on the firmness of Pink Lady apples (kgf), in 2002. Fruit was from twelve orchards in the Goulburn Valley and assessment was after 14 weeks air storage in a commercial cool store in the Goulburn Valley plus 1 day at 20^{o}C.

Orchard	Firmness (kgf) ± se[1]
1	7.2 ±0.18
2	7.2 ±0.12
3	6.8 ±0.15
4	6.1 ±0.13
5	6.8 ±0.16
6	6.3 ±0.10
7	6.9 ±0.21
8	7.5 ±0.05
9	7.4 ±0.13
10	7.4 ±0.06
11	6.9 ±0.11
12	6.4 ±0.14

[1] se = standard error of the mean

Table 6. Effect of maturity (1st harvest optimum physiological maturity) on the firmness of Pink Lady apples (kgf), in 2003. Fruit was from twelve orchards in the Goulburn Valley air storage cool store and assessment was after 12 weeks air storage in a commercial cool store in the Goulburn Valley plus 1 day at 20°C.

Orchard	Firmness (kgf) ± se[1]
1	7.1 ±0.15
2	6.4 ±0.10
3	6.5 ±0.08
4	7.0 ± 0.06
5	6.1 ± 0.01
6	Missing value
7	7.0 ±0.12
8	6.9 ±0.11
9	7.1 ±0.10
10	7.2 ±0.08
11	7.0 ±0.01
12	Missing value

[1] se = standard error of the mean

The missing values were due to a white fly outbreak at orchards 6 and 12. This fruit could not be commercially stored in the Goulburn Valley because of the risk introducing white fly.

Table 7. Effect of maturity (2nd harvest 'commercial') on the firmness of Pink Lady apples (kgf), in 2003. Fruit was from twelve orchards in the Goulburn Valley and assessment was after 12 weeks air storage in a commercial coolstore in the Goulburn Valley plus 1 day at 20°C.

Orchard	Firmness (kgf) ± se[1]
1	6.7 ±0.09
2	6.6 ±0.10
3	6.5 ±0.07
4	6.6 ±0.11
5	6.0 ±0.07
6	Missing value
7	6.9 ±0.10
8	7.3 ±0.06
9	6.7 ±0.06
10	7.2 ±0.09
11	6.9 ±0.06
12	Missing value

[1] se = standard error of the mean

The missing values were due to a white fly outbreak at orchards 6 and 12. This fruit could not be commercially stored in the Goulburn Valley because of the risk introducing white fly.

Table 8. Effect of maturity (1st harvest optimum physiological maturity) and 2nd harvest 'commercial') on the firmness of Pink Lady apples (kgf), in 2001. Fruit was from six orchards in the Goulburn Valley and assessment was after 24 weeks CA storage at DPI, Knoxfield plus 1 day at 20^{o}C.

Orchard	Maturity	
	1	2
1	8.1	7.8
2	7.8	7.5
3	7.7	6.7
4	8.3	8.0
5	7.4	7.1
6	7.7	7.1
LSD (*P=0.05*)[1]	0.4	

[1] Least significant difference of the means (5% level).

Table 9. Effect of maturity (1st harvest optimum physiological maturity and 2nd harvest 'commercial') on the firmness of Pink Lady apples (kgf), in 2002. Fruit was from twelve orchards in the Goulburn Valley and assessment was after 26 weeks CA storage at DPI, Knoxfield plus 1 day at 20^{o}C.

Orchard	Maturity	
	1	2
1	8.3	7.4
2	8.2	7.5
3	8.7	7.4
4	7.7	6.8
5	7.9	7.1
6	7.4	6.9
7	8.3	7.3
8	8.1	7.6
9	8.3	7.6
10	7.9	7.5
11	8.2	7.3
12	7.3	6.8
LSD (*P=0.05*)[1]	0.4	

[1] Least significant difference of the means (5% level).

Table 10. Effect of maturity (1st harvest optimum physiological maturity and 2nd harvest 'commercial') on the firmness of Pink Lady apples (kgf), in 2003. Fruit was from twelve orchards in the Goulburn Valley and assessment was after 26 weeks CA storage at DPI, Knoxfield plus 1 day at 20^{o}C.

Orchard	Maturity	
	1	2
1	7.5	7.2
2	7.6	7.0
3	7.8	7.3
4	7.8	7.5
5	6.8	6.8
6	7.8	7.4
7	8.1	7.9
8	7.9	7.8
9	8.0	7.7
10	7.9	7.9
11	7.7	7.4
12	7.8	7.7
LSD (*P=0.05*)[1]	0.5[2]	
	0.4[3]	

[1] LSD =Least significant difference of the means (5% level)
[2] Comparing means down a column at the same level of maturity.
[3] Comparing means across a row at the same level of orchard.

7.3 Experiment 2. Static simulated shipping experiment

INTRODUCTION

Shipping conditions may affect the firmness of apples during export from Australia to the UK. This was evident in some Pink Lady shipments to the UK in the year 2000, when fruit arrived soft. In these instances, the fruit was loaded within export specifications and poor shipping container temperature control was identified as a possible cause.

7.3.1 EXPERIMENTAL OBJECTIVE

To determine the effect of storage conditions, maturity and simulated shipping temperatures on Pink Lady apple firmness.

7.3.2 MATERIALS AND METHODS

Season 2001
Pink Lady apples were harvested from 6 orchards in the Goulburn Valley, with commercial harvest maturity (Section 6.2.4 Table 1). At each orchard, the fruit from each experimental block of trees were pooled and then 30 fruit were selected at random and placed in plastic mesh bags. The fruit was held temporarily in a commercial cool stored prior to transporting the fruit to DPI, Knoxfield. On arrival the replicate storage

bags were placed in either air or CA (2.5% O_2 plus 2% CO_2). After 12 weeks air storage or 17 weeks CA storage the bags of 30 fruit were divided into two bags of 15 fruit. One bag of the pair from each storage replicate was placed at 0°C the other at 4°C for 6 weeks (8 weeks for CA fruit) to simulate good and bad shipping temperature to the UK, followed by 6 days at 20°C to simulate marketing, before measuring fruit firmness.

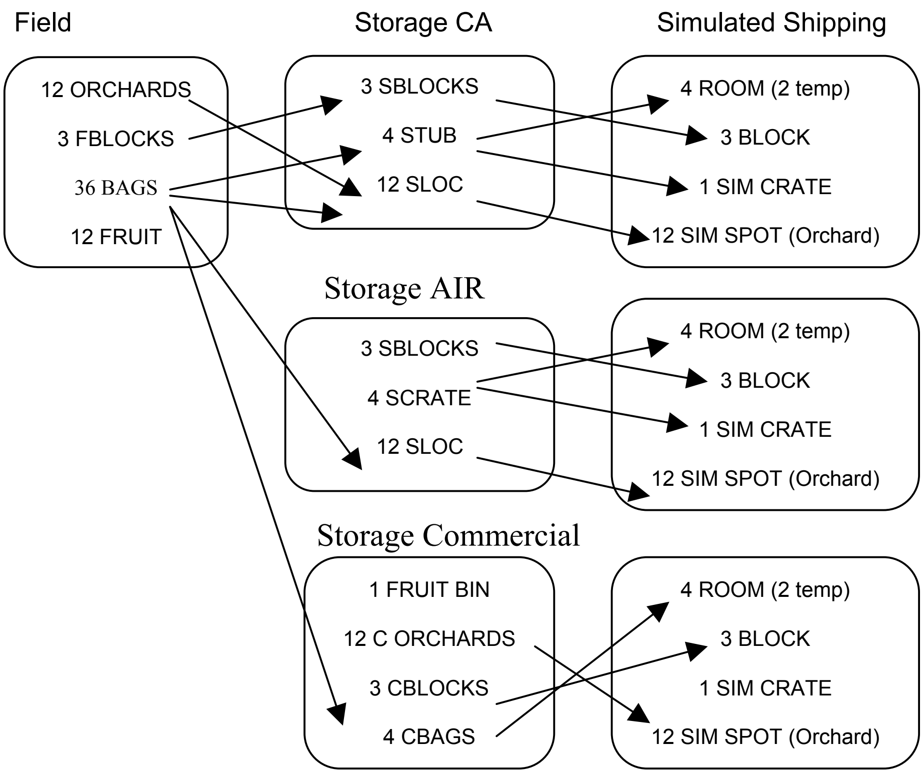
Season 2002
In 2002, the handling and storage were as reported for 2001 except that there were 12 orchards. The CA fruit were stored for 16 weeks not 17 weeks as in 2001.

In addition, fruit were also stored commercially for 10 weeks in air followed by 6 weeks simulated shipping at 0°C or 4°C plus 6 days at 20°C to simulate marketing.

Season 2003
In 2003, the handling and storage were as reported for 2002. Due to a fruit fly out-break in one region of the Goulburn Valley, fruit from orchards 6 and 12 were not included in the commercial storage trial.

Experimental design and statistical analysis

Figure 1. Diagram showing the three phases of the experimental design: Field, Storage and Simulated Shipping. The CA and AIR storage treatments were identical except for their storage container (ie. CA tub or High RH bag)



Letter codes were used to differentiate the phases for analysis.
F = field (example FBLOCK = field block)
S = storage (example SBLOCK = Storage block at DPI)
C = commercial (example CBLOCK = Commercial storage block)

Commercially stored fruit were not analysed as a three phase design because there was no block structure during the storage period (Fig. 1). Therefore, only standard errors of the means were used for comparing the differences in fruit firmness between orchards.

7.3.4 RESULTS

Static air storage experiment

In the static air storage experiment fruit from harvest 2 were stored 3 months in air followed by 6 weeks at 0°C or 4°C to simulate good and bad shipping temperatures then 6 days at 20°C to simulate marketing before the fruit firmness was measured.

Season 2001
In 2001, only fruit from orchard 2 stored in air and shipped at 4°C was significantly softer than fruit shipped at 0°C by approximately 0.3 kgf (Table 1)*.

Season 2002
In 2002, there was no significant effect of shipping temperature on firmness of air stored apples (Table 2).

Season 2003
In 2003, there was no significant effect of shipping temperature on firmness of air stored apples (Table 3).

Static commercial air storage experiment

In the static commercial air storage experiment fruit from harvest 2 were stored in a commercial cool room in the Goulburn Valley for 10 weeks in air, followed by 6 weeks at 0°C or 4°C to simulate good and bad shipping temperatures then 6 days at 20°C to simulate marketing before the fruit firmness was measured.

Season 2003
In 2002, the fruit was air stored commercially followed by simulated shipping outturned almost identically to the DPI static trial (see Table 4 and Table 2).

Static controlled atmosphere (CA) storage experiment

In the static CA storage experiment the fruit from harvest 2 were stored 16 to 17 weeks in air followed by 6-8 weeks at 0°C or 4°C to simulate good and bad shipping temperatures then 6 days at 20°C to simulate marketing before the fruit firmness was measured.

Season 2001
In 2001, there was no significant effect on CA stored fruit of shipping fruit at 4°C compared to 0°C on fruit firmness (Table 5).

Season 2002
In 2002, fruit from orchards 5, 6 and 8 after CA storage and simulated shipping at 4°C were significantly softer than fruit shipped at 0°C (Table 6). There was no significant effect of shipping temperature on the outturn firmness of fruit from the other orchards.

* All tables referenced are to be found within the current chapter.

Season 2003

In 2003, fruit from orchards 2,8 and 11 after CA storage and simulated shipping at 4°C were significantly softer than fruit shipped at 0°C (Table 7). There was no significant effect of shipping temperature on the outturn firmness of the other orchards.

7.3.5 TABLES

Table 1. Effect of simulated shipping temperature (0°C or 4°C) on firmness of fruit from six orchards from the Goulburn Valley (kgf), in 2001. Fruit was assessed after 12 weeks air storage plus 6 weeks simulated shipping and 6 days at 20°C to simulate marketing.

Orchard	Temperature	
	0°C	4°C
1	mv[4]	mv
2	7.0	6.7
3	6.3	6.1
4	7.4	7.2
5	mv	mv
6	6.7	6.6
LSD (*P=0.05*)[1]	0.1[2]	
	0.2[3]	

[1] Least significant difference of the means (5% level).
[2] Comparing means at the same level of grower.
[3] Comparing means at the same level of temperature.
[4] missing value

Table 2. Effect of simulated shipping temperature (0^oC or 4^oC) on firmness of fruit from twelve orchards from the Goulburn Valley (kgf), in 2002. Fruit was assessed after 12 weeks air storage plus 6 weeks simulated shipping and 6 days at 20^oC to simulate marketing.

Orchard	Temperature	
	0^oC	4^oC
1	7.1	7.2
2	6.8	7.0
3	6.7	7.1
4	6.5	6.4
5	7.2	6.8
6	6.5	6.3
7	7.0	6.9
8	7.6	7.2
9	8.0	7.9
10	7.7	7.3
11	6.9	6.9
12	6.6	6.8
LSD (*P=0.05*)[1]	0.3[2]	
	0.4[3]	

[1] Least significant difference of the means (5% level)
[2] Comparing means down a column at the same level of temperature.
[3] For all other comparisons.

Table 3. Effect of simulated shipping temperature (0^oC or 4^oC) on firmness of fruit from twelve orchards from the Goulburn Valley (kgf), in 2003. Fruit was assessed after 12 weeks air storage plus 6 weeks simulated shipping and 6 days at 20^oC to simulate marketing.

Orchard	Temperature	
	0^oC	4^oC
1	7.2	7.0
2	6.6	6.4
3	6.7	6.7
4	7.0	6.9
5	6.3	5.8
6	7.3	7.1
7	7.2	6.8
8	7.6	7.3
9	7.5	7.2
10	7.3	7.3
11	7.1	7.1
12	6.8	6.8
LSD (*P=0.05*)[1]	0.3[2]	

[1] Least significant difference of the means (5% level).
[2] Comparing means down columns or across rows.

Table 4. Effect of simulated shipping temperature (0°C or 4°C) on firmness of fruit from twelve orchards from the Goulburn Valley (kgf), in 2002. Fruit was assessed after 10 weeks commercial air storage plus 6 weeks simulated shipping and 6 days at 20°C to simulate marketing.

Orchard	Temperature ± se[1]	
	0°C	4°C
1	7.1 ± 0.11	7.2 ± 0.10
2	6.8 ± 0.11	7.0 ± 0.14
3	6.7 ± 0.14	7.1 ± 0.14
4	6.5 ± 0.10	6.4 ± 0.07
5	7.2 ± 0.15	6.8 ± 0.11
6	6.5 ± 0.07	6.3 ± 0.12
7	7.0 ± 0.09	6.9 ± 0.12
8	7.5 ± 0.14	7.1 ± 0.17
9	8.0 ± 0.16	7.9 ± 0.12
10	7.7 ± 0.11	7.3 ± 0.04
11	6.9 ± 0.09	6.8 ± 0.15
12	6.6 ± 0.05	6.8 ± 0.15

[1] se = standard error of the mean

Table 5. Effect of simulated shipping temperature (0°C or 4°C) on firmness of fruit from six orchards in the Goulburn Valley (kgf), in 2001. Fruit was assessed after 17 weeks CA storage plus 8 weeks simulated shipping and 6 days at 20°C to simulate marketing.

Orchard	Temperature	
	0°C	4°C
1	7.4	7.4
2	7.3	7.0
3	7.1	6.8
4	7.5	7.3
5	6.9	6.9
6	7.1	7.0
LSD (*P=0.05*)[1]	0.2[2]	

[1] Least significant difference of the means (5% level)
[2] Comparing means down columns with the same level of grower.

Table 6. Effect of simulated shipping temperature (0°C or 4°C) on firmness of fruit from twelve orchards in the Goulburn Valley (kgf), in 2002. Fruit was assessed after 16 weeks CA storage plus 6 weeks simulated shipping and 6 days at 20°C to simulate marketing.

Orchard	Temperature	
	0°C	4°C
1	7.8	7.7
2	8.0	7.8
3	7.8	7.8
4	7.6	7.4
5	7.9	7.3
6	7.2	6.7
7	7.8	7.7
8	8.2	7.5
9	8.0	8.0
10	8.1	8.1
11	7.6	7.4
12	7.3	7.1
LSD (*P=0.05*)[1]	0.5[2]	
	0.4[3]	

[1] LSD =Least significant difference of the means (5% level)
[2] Comparing means down a column at the same level of temperature.
[3] Comparing means across a row at the same level of orchard.

Table 7. Effect of simulated shipping temperature (0°C or 4°C) on firmness of fruit from twelve orchards from the Goulburn Valley (kgf), in 2003. Fruit was assessed after 16 weeks CA storage plus 6 weeks simulated shipping and 6 days at 20°C to simulate marketing.

Orchard	Temperature	
	0°C	4°C
1	7.3	7.2
2	7.4	7.0
3	7.4	7.3
4	7.7	7.5
5	6.7	6.7
6	7.8	7.5
7	7.8	7.5
8	7.9	7.3
9	7.9	7.7
10	7.8	7.7
11	7.7	7.2
12	7.7	7.3
LSD (*P=0.05*)[1]	0.5[2]	
	0.4[3]	

[1] LSD =Least significant difference of the means (5% level)
[2] Comparing means down a column at the same level of temperature.
[3] Comparing means across a row at the same level of orchard.

8. NUTRITION

8.1 Nutrition literature review

The mineral composition of fruit at harvest has a major influence on fruit firmness after storage. Effects of nutrients on fruit firmness has been reviewed by Sharples, 1980; DeEll et al. 2001, Johnston et al. 2002c, Little and Holmes, 2000 and will not be comprehensively reviewed for this report. In summary, apples with low calcium (Ca) and phosphorus (P) and high nitrogen (N) and potassium (K) concentrations in the flesh are not recommended for long-term storage (Faust and Shear, 1968, Sharples, 1980).

Timing of nutrient application is critical to optimising the nutrient levels in the fruit. The key nutrients at the bud burst, flowering and fruit set stages are Zinc and Boron (B). Both zinc and boron are needed for the growth and development of new tissue. They are essential for flower development and good fruit-set and they impact on fruit density (Smith, 1999). In the 1998/1999 Phosyn survey P and Zinc (Zn) were critically low in most of the orchards of Australia (Smith, 1999). During the vegetative growth stage zinc, manganese (Mn), magnesium (Mg) and iron (Fe) are the key nutrients in promoting good leaf and shoot growth and therefore fruit size and quality. During the fruit development stage the key elements are Calcium, Phosphorus, and Potassium (Phosyn Technical Bulletin, 2002). Calcium and phosphorus are the key nutrients for achieving firm fruit. During the six weeks after petal fall, cell division occurs in the developing fruits. During this period it is important to maximise the uptake of Calcium and phosphorus. Calcium increases firmness by cell to cell adhesion. Softening is characterised by changes in composition and structure in the cortical cell walls. These changes occur predominantly in the middle lamella region and results in loss of cell cohesion strength and textural quality. Calcium inhibits hydrolysis (breakdown) of pectin by the enzyme polygalacturonase (PG). The middle lamella, separates adjacent cells and serves as a bonding agent for cells and is rich in pectin. When the middle lamella is broken down the cells separate and firmness falls. Phosphorus is crucial for cell division, more cells means a denser, firmer fruit. Potassium and Calcium are both cations and as such excessive application of potassium should be avoided where calcium availability is known to be marginal. Softer, less dense fruit have tissue with larger cells and larger intercellular than fruit with smaller cells and less intercellular space (Harker et al. 1997).

Fruit with low numbers of cells and large cells are frequently shown to have lower concentrations of minerals important for storage performance, such as calcium (Little and Holmes 2000, p37). The occurrence of fruit that is unexpectedly soft can possibly be related back to mineral imbalance or deficiencies. However, the importance of tree habit and environmental factors cannot be overlooked (Harker et al. 1997). Research on Cox's Orange Pippin demonstrated the importance of cropload and time of thinning. The fruit were generally firmer if the thinning occurred between 5 and 15 days after full bloom (Johnson, 1992). This may reflect the importance of reducing flower number to improve calcium uptake. In general larger apples are softer than small (Blanpied et al. 1978). But, not always because it depends on the number of cells and cell size. Early thinning during cell division can result in larger fruit that are firmer. It is important to apply the calcium sprays in the 50 days after full bloom (DAFB) during the cell division phase to promote denser fruit. However, this will be influenced by the prevailing weather conditions.

Most calcium is acquired through water as it is drawn into the root system. When the trees water demand exceeds the supply from the soil (water stress) calcium uptake decreases (Chennell et al. 2002). In fruit trees, vegetative growth has priority over fruit for available calcium, particularly in stress situations. As the fruit takes up calcium from the tree system, calcium can migrate out of the fruit and back into the tree system. The transfer of calcium out of the fruit can be a problem if apples are harvested late and left to ripen or develop red colour (Smith, 1999). The best time to apply calcium sprays is petal fall to mid-December. As fruit expand in early December, actual calcium levels fall in the fruit due to the dilution associated with fruit expansion. From December, the only way to increase the calcium level in the fruit is by sprays or postharvest dips. When trees are sprayed with calcium, only that calcium which is deposited on the fruit is available for use by the fruit (Chennell et al. 2002). Penetration into the apple is slow and the growing cells quickly incorporate this calcium (Little and Holmes, 2000, p 80).

Postharvest dipping and vacuum infiltration with 4% calcium solutions have had consistent beneficial effects on maintaining firmness during storage (Harker et al. 2000). After storage calcium-treated fruit can be as much as 1.8 kgf firmer than undipped fruit Spartan apple firmness was improved by 0.4 kgf when the fruit was dipped in a 4% $CaCl_2$ solution after harvest (Mason et al. 1974). ‘Stopit’ applied at 0.45% as a postharvest drench increased the flesh firmness of Bonza and Golden Delicious apples by approximately 0.25 kgf (Little and Holmes, 2000, p229). However calcium chloride at > 0.9% to 4% can cause severe surface damage (Abbott et al. 1989, Little and Holmes, 2000, p 209). Apples are usually dipped the same day or within 24 hours of harvest at ambient temperature.

Calcium improves the storage performance of many fruits (Poovaiah et al. 1988). Ca-treated apples were firmer after storage than non-treated apples (Watkins et al. 1989). Calcium also slows down ethylene formation and respiration. Therefore ripening is slowed down. At harvest the average calcium level in Australian fruit as determined by Phosyn was only 3.8 mg/100 g fresh weight (FW) compared to a value of 5.4 for other countries (Smith, 1999). One possible explanation for low calcium concentration is because Australia follows a five-spray calcium program to control bitter pit, rather than a 10 spray program to improve storage life and market durability (pers. com. Colin Little).

The target mineral levels in fruit at harvest increase firmness and improve storeability and market durability should be as follows.

<u>Nitrogen (N)</u>
High nitrogen levels in fruit at harvest, by world standards are normally considered ideal at 40 to 50 mg/100 g FW but in Australia 17 mg/100g (0.017%) FW is considered normal (Smith, 1999). This probably reflects the generally held view that Pink Lady apples are sensitive to nitrogen and levels should be kept low. Colin Little’s mineral chart recommends that adequate level for nitrogen to be 0.18 to 0.23% dry weight (DW), see Appendix B, Table 1. High nitrogen in the fruit results in a low pulp density (larger cells) and therefore loss of firmness.

<u>Calcium (Ca)</u>
The target level for calcium at harvest is 5 mg/100 g (0.005%) FW (Sharples, 1980) or > 5 mg/100 g fresh weight (Smith, 1999). Colin Little’s mineral chart recommends the

adequate level for calcium to be 0.031% to 0.041% (percentage of the dry matter content) for long term CA storage. The mean N : Ca ratio approximately 10 to 14 (Sharples, 1980, Dris et al. 1998, Little and Holmes, 2000, p. 100).

Phosphorus (P)
The target level for phosphorus at harvest is 100 mg/100 g (Sharples, 1980) or >10 mg/100 g FW (Smith, 1999). Colin Little's mineral chart recommends the adequate level for phosphorus to be 0.06 to 0.08% DW.

Potassium (K)
The target level for potassium at harvest is 130 – 160 mg/100 g FW (Sharples, 1980) or 100 –120 mg/100 g FW (Smith, 1999). Colin Little's mineral chart recommends that adequate level for potassium to be 0.63 to 0.76% DW. The mean K : Ca ratio should not exceed 30 for good keeping quality (Faust and Shear, 1968). Little and Holmes, 2000, p.100 suggest that 30:1 is the ideal ratio.

Magnesium (Mg)
Magnesium 5 mg/100 g FW (Sharples, 1980) and less than 5 mg/100 g (Smith, 1999). Colin Little's mineral chart recommends that adequate level for magnesium to be 0.027 to 0.035% DW. If magnesium levels are too high it could reverse the Ca/Mg ratio and therefore reduce storability (Smith, 1999). The mean Ca : Mg 1:0.08 (Little and Holmes, 2000, p.100)

Zinc (Zn)
Zinc should be > 0.05 mg/100 g FW (Smith, 1999). Colin Little's mineral chart recommends that adequate level for zinc to be 5 to 10 parts per million (ppm) DW. Most Australian apple fruit have extremely low zinc levels at harvest (Smith, 1999).

Boron (B)
Boron should be 0.2 to 0.6 mg /100 g FW (Smith, 1999). Colin Little's mineral chart recommends that adequate level for boron to be 18 to 24 ppm (parts per millions dry weight).

Traditionally, analysis and interpretation of fruit samples are performed at harvest stage and thus analysis results indicating mineral deficiency cannot be corrected. Direct analysis of fruit samples at early growth and development stages was developed by Phosyn called the 'Early Season Fruitlet Analysis' (ESFA) technique which enables the grower to analyse his fruit at the 40- 50 gram stage and gain advance warning, in time to apply pre-harvest fertilizers to correct any potential nutrient imbalance (Ridings, 2002).

This project aims to correlate the nutrient status of Pink Lady apples at 20-25 grams, 40-50 grams and at harvest with the firmness outturn after storage and export. The project has been linked to Phosyn's nutritional research and Colin Little's Apple Maturity assessment work. AFFCO assisted by organising a shipment of Pink Lady to the UK where Ian Wilkinson determined the firmness of the fruit.

Sections 8.2 and 8.3 present the results which examine the benefits of using pre-harvest foliar sprays and post harvest calcium dipping to maximise nutrient levels in Pink Lady apples and their effect on firmness afterwards.

8.2 Effect of early season fruitlet nutrient analysis on Pink Lady apple firmness.

INTRODUCTION

Calcium , phosphorus, potassium and nitrogen levels in the fruit can have a major impact on apple firmness. Phosyn developed the 'Early Season Fruitlet Analysis' ESFA technique as a means of gaining advanced warning on the nutrient status of the fruit, in time to apply pre-harvest fertilisers to correct any potential nutrient imbalance. This project attempts to adapt the EFSA technique to Pink Lady apples.

The Pink Lady apple industry has two basic questions:
1) Does the fruit from orchards with soft fruit outturns have poor fruit nutrient status?
2) Can the nutrient status of the fruit be improved by using an ESFA approach for fruit nutrient status management?

8.2.1 EXPERIMENTAL OBJECTIVES

1. Determine the effect of foliar nutrients sprays on nutrient levels in Pink Lady apples.
2. Determine the correlation of Pink Lady apple fruit nutrient levels at 20-25 gram, 40-55 gram and at harvest with post storage firmness.

8.2.2 MATERIALS AND METHODS

Season 2001

Six orchards with 5 to 7 year old Pink Lady apple trees on MM106 rootstock were selected in the Goulburn Valley region.

At harvest a bulk sample of 20 fruit approximately 145 gram to 160 gram in weight were collected from each orchard for nutrient analysis at the 1st pick. The samples were analysed by the State Chemistry Laboratory, Victoria.

Season 2002

In year 2 the number of orchards was increased from six to twelve. The aim was to have five orchards using a modified Phosyn program (higher nutrient input) compared to 7 orchards using their normal spray programs (lower nutrient input.). The growers paid for the sprays.

The growers supplied the actual foliar spray records for the orchards used in this project. Nick Sanders, Phosyn Plc calculated the total amounts of each element applied during fruit growth period. The total amounts of nitrogen, calcium and phosphorus are presented in this report.

Products used by the growers were:

Orchard 1	Stopit, calcium chloride, Phoztrac, Caltrac, calcium nitrate Hydromag.
Orchard 2	Standard calcium program using Stopit.
Orchard 3	**High nutrient input**, full calcium program Stopit and Phoztrac for phosphorus and Zinc
Orchard 4	Stopit, Biomin calcium, Phoztrac, Calstop and Phozcare
Orchard 5	Calstop
Orchard 6	**High nutrient input**, Phoztrac, Pitstop, CaP, Caltrac 400, Seniphos, Mantrac and Coptrel
Orchard 7	Stopit program. Minimal zinc or phosphorus
Orchard 8	**High nutrient input**, Full calcium program with Phoztrac for additional zinc and phosphorus.
Orchard 9	**High nutrient input**, Bortrac, Stopit Caltrac, Phoztrac for additional zinc and phosphorus, Seniphos.
Orchard 10	**High nutrient input**, Phoztrac, Caltrac, Hydrophos, Stopit, calcium chloride, calcium nitrate, Seniphos, Hydromag, Budbuilder and Safe N
Orchard 11	Calstop and Biomin calcium
Orchard 12	Pitstop Phoztrac, Caltrac and Biomin calcium

At approximately the 25 gram fruitlet and 55 gram fruitlet stages a bulk sample of 12 fruit were collected from each orchard. The fruit was sampled from across the 5 field block replicates. At the first harvest (optimum physiological maturity) and at the second harvest (commercial harvest) a sample of 6 fruit by three fruit sizes (small with an average weight 137 grams, medium average weight 189 gram and large with an average weight 242 gram) were picked and their nutrient analysis determined by Phosyn analytical laboratory. It was felt after consultation with the growers and Phosyn that the effect of fruit size on the nutrient status of the fruit should be taken into account. There were differences in the fruits sizes between the orchards. However, the analysis of 2002 data found that fruit size was not having a significant effect on the nutrient status of the fruit at harvest with the exception of calcium. Larger fruit had significantly less calcium than the medium and small fruit, but based on Phosyn's and Colin Little's standards, the calcium levels for all sizes of fruit were within the adequate range for long term storage. Therefore, only data for medium sized fruit is presented in this report.

This project was not designed to establish optimum levels for nutrients in Pink Lady apples. There are commonly accepted standards for apples published in the scientific literature which identify normal levels in apples at harvest and target levels to maximise fruit firmness. Phosyn has established standards for their ESFA system. There are no specific mineral standards for Pink Lady apples. Therefore, generic mineral standards are used to determine if nutrition is a limiting factor in soft fruit at harvest and after storage. Ratings for interpreting the mineral levels in fruitlets, have been produced by Phosyn as a means of predicting the likelihood of fruit being soft after storage. At the 25 gram and 50 gram fruit stages there was one bulk sample analysis which came with Phosyn's ratings.

At harvest, five Phosyn analysis data sheets per orchard, that is the results of each field replicate, were provided by Phosyn. Ratings for interpreting the harvest sample results were taken from Phosyn's analysis sheets. The actual ratings used by Phosyn for interpreting results and recommending correctional foliar nutrient sprays is Phosyn's intellectual property and will not be presented. Similarly, the number of sprays and rates of products used for the Full Phosyn nutrient program is not presented as it is Phosyn's confidential information. However, readers wanting a guide as to foliar spray nutrient requirements (what products, application rates, how many sprays and what time of the year they were provided), the foliar spray program of orchard 1, for the season's 2001, 2002 and 2003 is provided (see Section 17.1 Appendix A Table 8). Orchard 1 fruit firmness picked at optimum physiological maturity (1st pick) met the proposed export standard of 7.5 kgf, after 6 months CA storage over the three seasons.

The nutritional levels of fruitlets at the 25 gram and 50 gram stages plus fruit at harvest were plotted against fruit firmness after 3 months and 6 months CA storage.

The results are interpreted using the fresh weight results because there were no dry weight standards for the 25 gram and 55 gram fruitlet stages. However, for the completeness of reporting the results, both dry weight and fresh weight data is presented for readers who may be more familiar with interpreting dry weight nutrient analysis (see Section 17.1 Appendix A, Tables 2 to 6).

Season 2003
In year 3, Phosyn plc provided free foliar nutrients to five orchards to apply nutrient program recommended by Phosyn (being the same orchards that used modified Phosyn nutrient programs in 2002) and the remaining seven orchards used their normal foliar spray programs.

Products used by the growers:

Orchard 1	Phoztrac, Caltrac, Seniphos and Calmax
Orchard 2	Bortrac, Stopit, Phoztrac, and Seniphos
Orchard 3	**Full Phosyn nutrient program**, Phoztrac, Stopit and Seniphos
Orchard 4	Stopit, Calmax, Caltrac and calcium chloride.
Orchard 5	Calmax, Calstop, Biomin calcium, CaP and Tracel SP.
Orchard 6	**Full Phosyn nutrient program**, Bortrac, Phoztrac, Calmax, Seniphos, Caltrac and Stopit.
Orchard 7	Bortrac, Stopit, Phoztrac and Seniphos.
Orchard 8	**Full Phosyn nutrient program**, Bortrac, Stopit, Phoztrac and Seniphos.
Orchard 9	**Full Phosyn nutrient program**, Bortrac, Zintrac, Phoztrac, Hydromag, Seniphos, Calmax and Stopit.
Orchard 10	**Full Phosyn nutrient program**, Bortrac, Phoztrac, Caltrac, Stopit, Seniphos, Budbuilder and Safe N.
Orchard 11	Calstop, Calmax, Biomin calcium, CaP, Trace SP.
Orchard 12	Pitstop, Tech-Gro Alpha, Caltrac and Nutrifol CaP

Fruitlets were collected for nutrient analysis at the 25 gram and 55 gram stages, a total of 50 fruitlets were collected at random from each orchard. In addition, at the first harvest a sample of 6 fruit per orchard replication block, of one fruit size, (medium with an average weight of 165 grams) were taken. The nutrient analysis was determined by Phosyn analytical laboratory.

The nutritional levels of fruitlets at the 25 gram and 50 gram stages plus fruit at harvest were plotted against fruit firmness after 3 months and 6 months CA storage.

8.2.3 RESULTS AND DISCUSSION

Season 2001
In 2001 the nutrient status of the fruit was measured at harvest to provide a base line for comparing the six orchards (Table 1)*.

The firmness of fruit from orchard 1 after 6 months CA storage plus 1 day at 20°C was 8.1 kgf, which is very good. If low nitrogen levels in Pink Lady apples are essential for firm fruit then orchard 1 meet the criteria (Table 1). It also had P, Ca, Mg and B in the adequate range for long term CA storage (LTCA). The N/Ca ratio was lower than the 10:1 ideal ratio for apples, which is good for maintaining fruit firmness. K levels were high but the K/Ca ratio was close to ideal and the Ca/Mg was also very good. S, Zn, Cu and Mn were slightly lower than the standards required for normal levels in the fruit at harvest for LTCA. In general, the nutritional status of the fruit from orchard 1 was close to ideal for LTCA. The fruit firmness was excellent for export, well above the proposed export standard of 7.5 kgf.

Orchard 4 had the firmest fruit after storage (8.3 kgf) but the fruit had slightly low calcium levels at harvest (Table 1). However, the fruit had good N/Ca ratios at 5.9:1 and a P/Ca ratio would have favoured firmer fruit. On the negative side the fruit had higher than ideal K/Ca ratio, which in theory would promote softer fruit. The fruit firmness was excellent for export, well above the proposed export standard of 7.5 kgf.

Orchard 5 had the softest fruit after storage and the fruit at harvest was nutritionally good (Table 1). Nitrogen levels in the fruit were low, P, Ca, Mg were normal, K was high but the K/Ca ratio was good. B was slightly high but was not expected to affect the fruit firmness after storage. All of the mineral ratios were good. The fruit firmness would not have met the proposed export standard of 7.5 kgf.

Orchard 2 fruit was slightly low in calcium at harvest, high in potassium and had a high K/Ca ratio and the N/Ca were normal (Table 1). The fruit firmness would have met the proposed export standard of 7.5 kgf.

Orchard 3 fruit had slightly high N levels in the fruit at harvest but in respect to all other minerals it was similar those in fruit from orchard 1 (Table 1). The fruit firmness would have met the proposed export standard of 7.5 kgf.

Orchard 6 fruit had a similar nutritional profile to orchard 1 but orchard 6 fruit was 0.4 kgf softer compared to orchard 1 after storage (Table 1). The fruit firmness would have met the proposed export standard of 7.5 kgf.

There were no significant relationships between any of the minerals or mineral ratios in the fruit at harvest and the firmness of the fruit after storage. The inability to achieve

* All tables referenced are to be found within the current chapter.

significant correlations between Ca and N levels in fruit at harvest and fruit firmness after storage is attributed to most fruit being within the normal expected ranges for long term storage or close to it. The absence of fruit with very low or high Ca and N levels meant that a significant line of fit was not possible.

Seasons 2002 and 2003

Nitrogen

Nitrogen applications are one of the most controversial nutrient inputs in apple production. The main concerns are the negative impacts of excessive nitrogen on fruit quality, especially colour but also on fruit firmness. Colour is important because delays in colour development can result in fruit with advanced maturity at harvest. Elevated nitrogen levels in the fruit dilute the benefits of calcium during ripening and result in a faster rate of softening during storage.

The nitrogen levels in the 25 gram and 55 gram fruitlets ranged from normal to very low (Tables 2a and 2b). Therefore, the growers were holding to the generally held concept that it is best to keep nitrogen levels low in Pink Lady apple to minimise the risk of getting soft fruit outturns. Most of the orchards applied 75% to 100% of the total seasons nitrogen input by 90 days after full bloom (DAFB).

In 2002, orchard 4 applied no nitrogen and N levels in the fruit remained very low in the fruitlets and fruit, which is good. In 2003, the orchard received a large application of calcium nitrate but the N levels remained normal to slightly low during the fruitlet and fruit stages. Significantly, 71.4% of the nitrogen was applied during the first 60 DAFB and this may explain why the N levels were similar to the N levels in fruit from the other 11 orchards which were rated as being slightly low which was on par for the other 11 orchards.

In general, the nitrogen levels in the fruit at the first pick were not substantially different to the 2nd pick for 2002 and 2003 harvest (Table 3a and 3b). Based on Phosyn standards for nitrogen in the fruit at harvest, the fruit N levels from most orchards ranged from slightly low to normal. The N levels were lower than the normally accepted target level of 40 to 50 mg/100 g FW. In both seasons the difference in nitrogen levels of the fruit at harvest did not reflect the difference in firmness after storage. There was no significant relationship between the nitrogen levels in the fruit at harvest and the firmness at harvest and after storage (data not presented).

Calcium

In general, fruit with more than 0.030 % dry weight or 4.38 mg / 100g FW are firmer. In this project we wanted to see if there were major differences in the calcium level in fruit from orchards with softer fruit compared to orchards with firmer fruit. In addition, we wanted to see if calcium foliar sprays applied to fruitlets with low calcium levels at the 25 gram stage could be corrected to normal levels and maintained at normal level at harvest.

It is important to get as much calcium as possible into the fruit during the cell division phase of the fruit development (50 DAFB). In 2002/2003 season orchards 6 and 12 increased the amount of calcium applied during the 60 DAFB compared to the 2001/2002 season and the firmness of the fruit after 6 months CA was improved substantially (Tables 3a, 3b, 5a and 5b). Orchards 5 and 11 received the same programs and only

5.8% of the season total calcium was applied in the 90 DAFB. Therefore, had orchard 5 applied more calcium during 90 DAFB this may have improved the firmness of the fruit. However, orchard 11 on the same spray program had acceptable firmness and orchard 5 did not. Orchard 4 had soft fruit in 2002 following low calcium input, but in 2003 the trees received 30% more Ca by 90 DAFB and the fruit was much firmer. Therefore, if 50% of the season's total calcium is applied by 90 DAFB it may improve the chance of firmer fruit after long term storage, particularly if the fruit is harvested at 'commercial' harvest (Tables 3a and 3b). More work over a number of seasons is required to substantiate this observation.

In 2001/2002, orchards 9 and 10 results showed normal ratings for calcium at the 55 gram fruitlet stage, normal to high ratings at harvest with very good N : Ca ratios less than 4 and the fruit firmness after long term storage was very good. However, orchards 11 and 12 tell a different story. They had low to slightly low calcium ratings at the 55 gram fruitlet stage, less than normal calcium ratings at harvest with high N : Ca ratios. Orchard 12 fruit was soft after storage compared to orchard 10 however orchard 11 fruit was not softer. This would suggest that factors other than calcium and nitrogen in the fruit were having an effect on the firmness of fruit from orchard 12 after storage.

In general, the calcium ratings improved from the 25 gram to 55 gram stages irrespective of the high or lower inputs of calcium (Table 5a and 5b). There is no evidence to suggest the early ESFA doesn't work because in the higher calcium input orchards, calcium ratings improved between the 25 gram and 55 gram stages. Orchardists should know the calcium status of the fruit as early as possible to allow sufficient time to correct any calcium deficiency.

It is generally accepted that fruit with calcium levels greater than 5 mg / 100 g FW at harvest are likely to outturn firmer than fruit with less than 5 mg / 100 g FW. The ideal N : Ca ratio for apples is considered to be 10:1 for apples. However, because Pink Lady apples are thought to be more sensitive to nitrogen than other apple varieties the target N level in the fruit is kept lower thus the Ca : N ratio is lower. However, the results from this project suggest that the 40 to 50 mg /100 g FW international benchmark of Ca and the 10:1 N : Ca ratio may be safe for Pink Lady apples. However, more work is needed over a number of seasons to determine how sensitive Pink Lady apple is to nitrogen levels in the fruit at harvest and its effect on fruit firmness.

In both seasons the difference in Ca levels of the fruit at harvest did not reflect the difference in firmness of the fruit after storage. There was no significant relationship between the calcium levels in the fruit at harvest and the firmness at harvest and after storage (data not presented).

Calcium is important for return bloom. Orchard 10 was able to have two consecutive high cropping years in 2002 and 2003 because the trees had reduced tree vigour coupled with a high calcium to nitrogen ratio in both years (see Section 9.2.4 Tables 1 and 2). In both years the calcium level at the 25 gram and 55 gram fruitlets stages were slightly low to low but by harvest the levels were normal to high. In both years the firmness at harvest and after storage was good (Table 5 b).

Phosphorus

The P levels in the fruit at the 55 gram fruitlet stage ranged from very low to low across the orchards (Table 6a and 6b). No orchards had normal P levels at the 55 gram fruitlet stage. Most orchards applied 50% or more of the season total P by 90 DAFB. At harvest the P levels in the fruit from some orchards were less than normal. However, there was no significant relationship between low and normal levels of P levels in relation to fruit firmness after storage (data not presented).

In this project the amount of P applied from foliar sprays, ranged from none up to 13.17 kg per hectare. Orchards 4,5 and 11 applied no P in 2002 and 2003 and the fruit at harvest still achieved normal levels of P. P was not applied to the soil at these orchards in 2002 and 2003. Included in Section 17.2 Appendix B, Table 7 are the results of soil analyses taken from each orchard in June 2002. The data is presented for readers wishing to know the soil nutritional status of the orchards. There was no obvious difference in the soil P levels at orchards 4,5 and 11 compared to the other orchards. This may explain why the fruit P levels were normal at harvest.

Colour of the fruit was not measured as part of this project. But it would be interesting to know what effect the N : P rating has on the skin red blush. Potentially, earlier colour may enable the grower to pick his fruit earlier and thus the fruit could be closer to optimum maturity for long term CA storage.

Most orchards had normal or slightly high N : P ratios. Whilst some orchards had higher than normal levels of N : P in the fruit at harvest, this did not translate into softer fruit.

8.2.4 TABLES

Table 1. Nutrient status (N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulphur, Zn = zinc, Mn = manganese and B = boron) of Pink Lady apple fruits at harvest (Dry weight basis) from six orchards in the Goulburn Valley.

Nutrient level (% or ppm)[1]	Orchard					
	1	2	3	4	5	6
N %	0.132	0.175	0.227	0.159	0.131	0.187
P %	0.073	0.072	0.068	0.085	0.077	0.065
K %	0.899	0.959	0.851	1.08	0.915	0.893
Ca %	0.033	0.023	0.030	0.027	0.033	0.032
Mg %	0.032	0.032	0.032	0.038	0.029	0.032
S %	0.012	0.022	0.020	0.021	0.017	0.017
Zn ppm	1.71	2.08	2.79	2.12	1.94	1.95
Cu ppm	0.05	0.71	3.04	0.05	2.16	0.05
Mn ppm	2.53	3.18	2.52	2.18	2.46	2.21
B ppm	20.7	20.3	26.3	29.8	34.2	22.3
N : Ca ratio[2]	4.0:1	7.6:1	7.6:1	5.9:1	4.0:1	5.8:1
K : Ca	27.2	41.7	28.4	40.0	27.7	27.9
P : Ca	2.2	3.1	2.3	3.2	2.3	2.0
Ca : Mg	1.0	0.7	0.9	0.7	1.1	1.0
	Firmness (kgf)[3]					
	8.1	7.8	7.7	8.3	7.4	7.7

[1] % = Percentage of the dry matter content and ppm = part per million.
[2.] Ideal mineral ratios are N : Ca 10 : 1, K : Ca 30 : 1, P : Ca 2.2 : 1, Ca : Mg 1: 0.08 (Little and Holmes 2000, p100)
[3] Firmness of the fruit from 6 orchards, after 6 months CA storage plus 1 day at 20°C.

The mineral standards used in this report were based on standards provided by Colin Little "Mineral assessment on apple fruit 145 to 160 gram weight taken at optimum maturity for long term CA storage" (see Section 17.1 Appendix A Table 1).

Normal levels at harvest for long-term controlled atmosphere storage (LTCA) are:

- Nitrogen: 0.17 to 0.21% (The adequate level was lowered by comparison with the generic apple standards Appendix B Table 2, for Pink Lady apples on advice from Colin Little). Fruit with levels higher than 0.21 increase the risk of getting softer fruit after storage.
- Phosphorus: 0.06 to 0.08%. Fruit with levels lower than 0.06 increase the risk of getting softer fruit after storage.
- Potassium: 0.63 to 0.76%. Fruit with levels higher than 0.76 increase the risk of getting softer fruit after storage.
- Calcium: 0.031 to 0.041%. Fruit with levels lower than 0.031 increase the risk of getting softer fruit after storage.
- Magnesium: 0.027 to 0.035%. Fruit with levels higher than 0.035 increase the risk of getting softer fruit after storage.
- Sulphur: 0.03 to 0.05 % is considered normal for apples.

The following trace elements at deficient or excess levels are not normally associated with soft fruit. It is considered to be on the safe side and have them within the normal levels cited below.

- Zinc: 5 to 10 ppm is considered normal for apples.
- Copper: 7 to 9 ppm is considered normal for apples.
- Manganese: 7 to 15 ppm is considered normal for apples.
- Boron: 18 to 24 ppm is considered normal for apples.

Table 2a. Total quantity of **nitrogen** applied during the 60 days and 90 days after full bloom (DAFB) and the total amount for the season applied during the fruit growth period (full bloom to harvest) and the fruitlet analysis for orchards 1 to 6 in the 2002 and 2003 harvest seasons.

Orchard and Harvest Year	November 60 DAFB[1]		FRUITLET 25gram[3]			December 90 DAFB		FRUITLET 55gram[1]			Season total nitrogen	
	Quantity[2] grams	Seasonal[3] percentage	Nitrogen[4] mg/100g FW	Rating[5]	Actual[1] Fruitlet weight	Quantity[2] grams	Seasonal[3] percentage	Nitrogen[4] mg/100g FW	Rating[5]	Actual[1] Fruitlet weight	Quantity[2] grams	Seasonal[3] percentage
Orchard 1												
2002	1035g	75%	74.4	V-LOW	18.8g	1380g	100%	44	V-LOW	51.3g	1380g	100%
2003	1036g	75%	65.7	S-LOW	28g	1381g	100%	28.9	LOW	70.5g	1381g	100%
Orchard 2												
2002	1035g	49.2%	96.1	V-LOW	17.1g	1553g	74%	48.7	LOW	50.1g	2105g	100%
2003	1863g	77.1%	100	NORMAL	27.1g	2415g	100%	39.9	S-LOW	65.2	2415g	100%
Orchard 3												
2002	1725g	55.%	78.5	V-LOW	15.3	3105g	100%	48.4	LOW	55g	3105g	100%
2003	1760g	83.6%	110.5	NORMAL	25.4	2105g	100%	59.3	NORMAL	60g	2105g	100%
Orchard 4												
2002			76	V- LOW	13.5g			38.2	V-LOW	48.6g		
2003	77500g	71.4%	93	NORMAL	24.1g	108500g	100%	40.7	S-LOW	63g	108500g	100%
Orchard 5												
2002	none	none	95.8	V-LOW	15.5g	none	none	43.2	V-LOW	50.9g	none	
2003	none	none	85.7	S-LOW	23.8g	none	none	33.5	LOW	59.5g	1000g	100%
Orchard 6												
2002	404g	9.1%	105.5	LOW	23.6g	1294g	29%	60.6	S-LOW	60.6g	4404g	100%
2003	1621g	62.7%	82.3	NORMAL	30.9g	2587g	100%	34.5	LOW	68.7g	2587g	100%

1. Fruitlet 25 gram and 55 gram were the target weights and the actual fruitlet weights are the average fruitlet weights as measured for each orchard.
2. Quantity grams = the accumulated total amount of nitrogen applied in the 60 DAFB, 90 DAFB and the total amount applied during the season.
3. Seasonal percentage = the accumulated percentage of the total amount of nitrogen applied during the fruit growth period (flowering to harvest) for nitrogen.
4 Nitrogen level (fresh weight weight analyses = FW) in the fruitlets at the '25 gram' and '55 gram stages.
5. Ratings for the nitrogen level in fruitlets at the 25 gram and 55 gram stages, as set by the Phosyn analysis standards are V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. High nitrogen levels in fruitlets if not corrected increase the risk of soft fruit after storage. The actual high value is Phosyn's confidential information.

Table 2b. Total quantity of **nitrogen** applied during the 60 days and 90 days after full bloom (DAFB) and the total amount applied during the fruit growth period (full bloom to harvest) and the fruitlet analysis for orchards 7 to 12 in the 2002 and 2003 harvest seasons.

Orchard and Harvest Year	November 60 DAFB[1]		FRUITLET 25gram[3]			December 90 DAFB		FRUITLET 55gram[1]			Season total nitrogen	
	Quantity[2] grams	Seasonal[3] percentage	Nitrogen[4] mg/100g FW	Rating[5]	Actual[1] Fruitlet weight	Quantity[2] grams	Seasonal[3] percentage	Nitrogen[4] mg/100g FW	Rating[5]	Actual[1] Fruitlet weight	Quantity[2] grams	Seasonal[3] percentage
Orchard 7												
2002	1035g	49.2%	113.1	V-LOW	16.5g	1553g	74%	55.3	LOW	51.8g	2105g	100%
2003	1863g	77.1%	125.9	HIGH	29.3g	2415g	100%	58.8	NORMAL	65g	2415g	100%
Orchard 8												
2002	1035g	49.%	70.5	V-LOW	14.4g	1553g	74%	38.7	V-LOW	48g	2105g	100%
2003	1863g	77.10%	71.6	NORMAL	33.8g	2415g	100%	26	LOW	79.8g	2415g	100%
Orchard 9												
2002	946g	36.4%	50.7	V-LOW	15.6g	2326g	89%	31.7	V-LOW	51.9g	2602g	100%
2003	2664g	65.9%	59.8	LOW	23.6g	4044g	100%	27.8	LOW	65.6g	4044g	100%
Orchard 10												
2002	518g	27.3%	39.1	V-LOW	16g	1208g	64%	29.8	V-LOW	45.8g	1898g	100%
2003	3176g	87.4%	56.5	LOW	26.5g	3635g	100%	21.7	V-LOW	63.9g	3635g	100%
Orchard 11												
2002	none	none	102.1	V-LOW	18.4g	none	none	55	LOW	52.3g		
2003	none	none	87.6	NORMAL	27.3g	none	none	41.2	NORMAL	81.6g	1000g	100%
Orchard 12												
2002	320g	10.6%	99.2	LOW	21.6g	1020g	34%	59.6	LOW	55g	3018g	100%
2003			96.1	NORMAL	31.1g	120g	100%	38.9	S-LOW	73.6g	120g	100%

1. Fruitlet 25 gram and 55 gram were the target weights and the actual fruitlet weights are the average fruitlet weights as measured for each orchard.
2. Quantity grams = the accumulated total amount of nitrogen applied in the 60 DAFB, 90 DAFB and the total amount applied during the season.
3. Seasonal percentage = the accumulated percentage of the total amount of nitrogen applied during the fruit growth period (flowering to harvest) for nitrogen.
4. Nitrogen level (fresh weight weight analyses = FW) in the fruitlets at the '25 gram' and '55 gram stages.
5. Ratings for the nitrogen level in fruitlets at the 25 gram and 55 gram stages, as set by the Phosyn analysis standards are V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. High nitrogen levels in fruitlets if not corrected increase the risk of soft fruit after storage. The actual high value is Phosyn's confidential information.

Table 3a. **Nitrogen** (fresh weight analysis) for fruit from the 1st harvest and 2nd harvests for orchards 1 to 6 in 2002 and 2003 harvests and the firmness at harvest and after 6 months controlled atmosphere (CA) storage.

Orchard and Harvest Year	Mineral levels at HARVEST				Firmness kgf			
	Nitrogen mg/100g FW 1st pick	Rating[1]	Nitrogen mg/100g FW 2nd pick	Rating	HARVEST 1st pick	HARVEST 2nd pick	After CA-storage (6 months) 1st pick	After CA-storage (6 months) 2nd pick
Orchard 1								
2002	24.2	S-LOW	23.5	S-LOW	10.2	9.2	8.3	7.4
2003	26.6	S-LOW	25.9	S-LOW	7.8	7.6	7.5	7.2
Orchard 2								
2002	39.1	S-HIGH	33.3	NORMAL	10.3	8.8	8.2	7.5
2003	32.1	NORMAL	30.7	NORMAL	8.2	7.8	7.6	7.0
Orchard 3								
2002	34.4	NORMAL	32.1	NORMAL	10.1	9.4	8.7	7.3
2003	47.9	S-HIGH	44.1	NORMAL	8.3	7.2	7.8	7.3
Orchard 4								
2002	22.5	S-LOW	25.7	S-LOW	9.4	8.1	7.7	6.8
2003	28.2	S-LOW	28.4	NORMAL	8.4	8.4	7.8	7.5
Orchard 5								
2002	30.4	NORMAL	32.8	NORMAL	10.0	8.8	7.9	7.1
2003	28.9	NORMAL	27.7	S-LOW	7.2	6.9	6.8	6.8
Orchard 6								
2002	36.9	S-HIGH	38.8	S-HIGH	8.6	8.2	7.4	6.9
2003	32.4	NORMAL	36.1	NORMAL	8.1	7.7	7.8	7.3

The target levels for nitrogen in apples based on world standards is 40 to 50 mg/100g FW (Smith, 1999).
Values greater than 50 mg/100g are likely to have softer fruit than fruit with less than 50 mg/100g.
[1.] Ratings for the nitrogen level in fruit at harvest based on Phosyn analysis results, V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Normal N levels in the fruit at harvest are 28.4 to 36.1 mg/100 g FW.

Table 3b. **Nitrogen** (wet weight analysis) for fruit from the 1st harvest and 2nd harvests for orchards 7 to 12 in 2002 and 2003 harvests and the firmness at harvest and after 6 months controlled atmosphere (CA) storage.

Orchard and Harvest Year	Mineral levels at HARVEST				Firmness kgf			
	Nitrogen mg/100g FW 1st pick	Rating[1]	Nitrogen mg/100g FW 2nd pick	Rating	HARVEST 1st pick	HARVEST 2nd pick	After CA-storage (6 months) 1st pick	After CA-storage (6 months) 2nd pick
Orchard 7								
2002	44.2	S-HIGH	41.6	S-HIGH	10.2	9.2	8.3	7.4
2003	36.9	S-HIGH	38.8	S-HIGH	7.8	7.6	7.5	7.2
Orchard 8								
2002	27.0	S-LOW	28.3	NORMAL	10.3	8.8	8.2	7.5
2003	31.7	NORMAL	31.3	NORMAL	8.2	7.8	7.6	7.0
Orchard 9								
2002	22.1	S-LOW	24.5	S-LOW	10.1	9.4	8.7	7.3
2003	27.3	S-LOW	26.0	S-LOW	8.3	7.2	7.8	7.3
Orchard 10								
2002	14.1	V-LOW	15.9	V-LOW	9.4	8.1	7.7	6.8
2003	13.4	V-LOW	21.8	S-LOW	8.4	8.4	7.8	7.5
Orchard 11								
2002	43.3	S-HIGH	43.2	S-HIGH	10.0	8.8	7.9	7.1
2003	38.8	NORMAL	33.3	NORMAL	7.2	6.9	6.8	6.8
Orchard 12								
2002	47.1	S-HIGH	47.5	S-HIGH	8.6	8.2	7.4	6.9
2003	41.1	S-HIGH	38.0	NORMAL	8.1	7.7	7.8	7.3

The target levels for nitrogen in apples based on world standards is 40 to 50 mg/100g FW (Smith, 1999).
Values greater than 50 mg/100g are likely to have softer fruit than fruit with less than 50 mg/100g.
[1.] Ratings for the nitrogen level in fruit at harvest based on Phosyn analysis results, V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Normal N levels in the fruit at harvest are 28.4 to 36.1 mg/100 g FW.

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Table 4a. Total quantity of **calcium** applied during the 60 days and 90 days after full bloom (DAFB) and the total amount applied during the fruit growth period (full bloom to harvest) and the fruitlet analysis for orchards 1 to 6 in the 2002 and 2003 harvest seasons.

Orchard and Harvest Year	November 60 DAFB		FRUITLET 25gram[1]		December 90 DAFB		FRUITLET 55gram[1]		Season total Calcium	
	Quantity[2] grams	Seasonal[3] percentage	Calcium mg/100g FW	Rating[4]	Quantity[2] grams	Seasonal[3] percentage	Calcium mg/100g FW	Rating[4]	Quantity[2] grams	Seasonal[3] percentage
Orchard 1										
2002	9120g	68.5%	18.4	NORMAL	12120g	91.0%	10.9	NORMAL	13320g	100%
2003	7700g	38.3%	8.8	LOW	10844g	53.0%	7.5	S-LOW	20128g	100%
Orchard 2										
2002	6696g	51.9%	13.3	LOW	8196g	63.5%	10	NORMAL	12911g	100%
2003	5440g	28.4%	11.7	S-LOW	8555g	44.7%	8.3	NORMAL	19160g	100%
Orchard 3										
2002	5000g	23.3%	18.1	NORMAL	9000g	41.9%	10.8	NORMAL	21460g	100%
2003	5000g	32.%	7.5	V-LOW	8020g	52.3%	6	LOW	15338g	100%
Orchard 4										
2002	1650g	26.3%	18.4	NORMAL	3825g	61.0%	9.2	S-LOW	6275g	100%
2003	2400g	20.6%	12.7	S-LOW	3600g	30.8%	8.2	S-LOW	11670g	100%
Orchard 5										
2002	3200g	33.3%	17.9	NORMAL	4800g	50.0%	10.4	NORMAL	9600g	100%
2003	300g	2.9%	12.7	S-LOW	600g	5.8%	8.4	S-LOW	10280g	100%
Orchard 6										
2002	3368g	11.9%	12.2	S-LOW	6932g	24.6%	7.5	LOW	28175g	100%
2003	4200g	22.3%	8.7	LOW	7000g	37.2%	7.6	S-LOW	18803g	100%

1. Fruitlet 25 gram and 55 gram were the target weights.
2. Quantity grams = the accumulated total amount of calcium applied in the 60 DAFB, 90 DAFB and the total amount applied during the season.
3. Seasonal percentage = the accumulated percentage of the total amount of calcium applied during the fruit growth period (flowering to harvest) for calcium at 60 DAFB, 90 DAFB and total for season.
4. Ratings for the calcium level in fruitlets at the 25 gram and 55 gram stages, as set by the Phosyn analysis standards are V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Low calcium levels in fruitlets if not corrected increase the risk of soft fruit after storage. The actual low value is Phosyn's confidential information.

Table 4b. Total quantity of **calcium** applied during the 60 days and 90 days after full bloom (DAFB) and the total amount applied during the fruit growth period (full bloom to harvest) and the fruitlet analysis for orchards 7 to 12 in the 2002 and 2003 harvest seasons.

Orchard and Harvest Year	November 60 DAFB		FRUITLET 25gram[1]		December 90 DAFB		FRUITLET 55gram[1]		Season total Calcium	
	Quantity[2] grams	Seasonal[3] percentage	Calcium mg/100g FW	Rating[4]	Quantity[2] grams	Seasonal[3] percentage	Calcium mg/100g FW	Rating[4]	Quantity[2] grams	Seasonal[3] percentage
Orchard 7										
2002	6696g	51.9%	14.8	S-LOW	8196g	63.5%	8.2	S-LOW	12911g	100%
2003	5440g	28.4%	10.1	LOW	8555g	44.7%	7.6	S-LOW	19160g	100%
Orchard 8										
2002	6696g	51.9%	22.3	NORMAL	8196g	63.5%	13.2	NORMAL	12911g	100%
2003	5440g	28.4%	10.6	S-LOW	8555g	44.7%	8.2	NORMAL	19160g	100%
Orchard 9										
2002	2000g	15.6%	16.1	S-LOW	6000g	46.8%	10.4	NORMAL	12820g	100%
2003	6000g	25.3%	11.1	LOW	10000g	42.2%	9.1	NORMAL	23720g	100%
Orchard 10										
2002	7680g	54.5%	17.3	NORMAL	10680g	75.9%	13.2	NORMAL	14080g	100%
2003	11280g	48.3%	10.8	LOW	15296g	65.5%	8.4	NORMAL	23354g	100%
Orchard 11										
2002	3200g	33.3%	15.2	S-LOW	4800g	50.0%	8.5	S-LOW	9600g	100%
2003	300g	2.9%	10.6	LOW	600g	5.8%	5.9	LOW	10280g	100%
Orchard 12										
2002	2662g	16.1%	12.6	S-LOW	4690g	28.4%	6.9	LOW	16518g	100%
2003	2993g	20.6%	9.1	LOW	4947g	34.1%	6.6	S-LOW	14514g	100%

1. Fruitlet 25 gram and 55 gram were the target weights.
2. Quantity grams = the accumulated total amount of calcium applied in the 60 DAFB, 90 DAFB and the total amount applied during the season.
3. Seasonal percentage = the accumulated percentage of the total amount of calcium applied during the fruit growth period (flowering to harvest) for calcium at 60 DAFB, 90 DAFB and total for season.
4. Ratings for the calcium level in fruitlets at the 25 gram and 55 gram stages, as set by the Phosyn analysis standards are V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Low calcium levels in fruitlets if not corrected increase the risk of soft fruit after storage. The actual low value is Phosyn's confidential information.

Table 5a. **Calcium** and **nitrogen / calcium ratios** (N/Ca wet weight analysis) for fruit from the 1st harvest and 2nd harvests for orchards 1 to 6 in 2002 and 2003 harvests and the firmness at harvest and after 6 months controlled atmosphere (CA) storage.

Orchard and Harvest year	Mineral levels and ratios at HARVEST								Firmness kgf			
	Calcium mg/100g FW 1st pick	Rating[1]	Calcium mg/100g FW 2nd pick	Rating[1]	N/Ca ratio 1st pick	Rating	N/Ca ratio 2nd pick	Rating	HARVEST 1st pick	HARVEST 2nd pick	After CA-storage (6 months) 1st pick	After CA-storage (6 months) 2nd pick
Orchard 1												
2002	7.5	HIGH	6.4	NORMAL	3.2	NORMAL	3.6	NORMAL	10.2	9.2	8.3	7.4
2003	5.4	NORMAL	6.1	NORMAL	4.4	NORMAL	4.2	NORMAL	7.8	7.6	7.5	7.2
Orchard 2												
2002	3.8	LOW	4.8	S-LOW	10.3	HIGH	6.9	S-HIGH	10.3	8.8	8.2	7.5
2003	4.8	S-LOW	4.4	S-LOW	7.3	S-HIGH	7.0	S-HIGH	8.2	7.8	7.6	7.0
Orchard 3												
2002	5.5	NORMAL	4.8	S-LOW	6.3	NORMAL	6.7	S-HIGH	10.1	9.4	8.7	7.3
2003	5.5	NORMAL	4.5	S-LOW	10.6	HIGH	9.7	HIGH	8.3	7.2	7.8	7.3
Orchard 4												
2002	3.9	LOW	3.8	LOW	5.8	NORMAL	6.7	S-HIGH	9.4	8.1	7.7	6.8
2003	4.5	S-LOW	4.2	S-LOW	6.7	S-HIGH	6.7	S-HIGH	8.4	8.4	7.8	7.5
Orchard 5												
2002	4.8	S-LOW	4.8	S-LOW	6.3	NORMAL	6.8	S-HIGH	10.0	8.8	7.9	7.1
2003	7.2	S-HIGH	6.1	NORMAL	4.7	NORMAL	4.5	NORMAL	7.2	6.9	6.8	6.8
Orchard 6												
2002	5.2	NORMAL	4.1	S-LOW	7.1	S-HIGH	9.6	HIGH	8.6	8.2	7.4	6.9
2003	6.0	NORMAL	6.1	NORMAL	5.3	NORMAL	6.0	NORMAL	8.1	7.7	7.8	7.3

The target level for calcium in the fruit at harvest is greater than 5 mg/100g FW (Smith, 1999). Values greater than 5 mg/100g are likely to have firmer fruit.

Nitrogen to calcium (N : Ca) ratio 10:1 is considered ideal (Little and Holmes 2000, p100). Ratios greater than 10:1 increase the risk of soft fruit after storage.

[1]. Ratings for the calcium level and N/Ca ratio in fruit at harvest based on Phosyn analysis results, V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Normal Ca levels in the fruit at harvest are 4.83 to 6.45 mg / 100g FW. Very low levels of (3.5 mg / 100 g FW). Normal ratios in fruit at harvest are 1.99 to 6.3. High N : Ca (> 7) in fruit at harvest increase the risk of soft fruit after storage.

Table 5b. **Calcium** and **nitrogen / calcium** ratios (N/Ca wet weight analysis) for fruit from the 1st harvest and 2nd harvests for orchards 7 to 12 in 2002 and 2003 harvests and the firmness at harvest and after 6 months controlled atmosphere (CA) storage.

Orchard and Harvest year	Mineral levels and ratios at HARVEST								Firmness kgf			
	Calcium mg/100g FW 1st pick	Rating[1]	Calcium mg/100g FW 2nd pick	Rating[1]	N/Ca ratio 1st pick	Rating	N/Ca ratio 2nd pick	Rating	HARVEST 1st pick	HARVEST 2nd pick	After CA-storage (6 months) 1st pick	After CA-storage (6 months) 2nd pick
Orchard 7												
2002	3.2	LOW	3.9	LOW	13.8	V-HIGH	7.6	S-HIGH	9.8	8.5	8.3	7.3
2003	4.4	S-LOW	4.1	S-LOW	9.0	HIGH	6.7	S-HIGH	8.4	8.2	8.1	7.8
Orchard 8												
2002	5.4	NORMAL	5.2	NORMAL	5.0	NORMAL	3.2	NORMAL	10.7	8.8	8.0	7.6
2003	4.5	S-LOW	4.6	S-LOW	6.9	S-HIGH	2.9	NORMAL	8.2	8.1	7.9	7.8
Orchard 9												
2002	6.2	NORMAL	5.1	NORMAL	3.6	NORMAL	3.1	NORMAL	10.2	8.9	8.3	7.6
2003	5.8	NORMAL	6.5	NORMAL	4.2	NORMAL	3.0	NORMAL	8.0	7.9	8.0	7.7
Orchard 10												
2002	6.8	NORMAL	7.7	S-HIGH	2.1	NORMAL	2.3	NORMAL	10.1	9.2	7.9	7.5
2003	6.9	S-HIGH	6.0	NORMAL	2.2	NORMAL	2.3	NORMAL	8.1	7.9	7.9	7.8
Orchard 11												
2002	3.7	LOW	3.9	LOW	11.7	HIGH	6.7	S-HIGH	9.9	8.8	8.2	7.3
2003	4.5	S-LOW	4.7	S-LOW	8.3	S-HIGH	6.5	S-HIGH	7.4	7.7	7.7	7.4
Orchard 12												
2002	3.6	LOW	3.6	LOW	13.1	V-HIGH	7.9	HIGH	9.4	8.9	7.3	6.8
2003	5.0	NORMAL	4.7	S-LOW	8.7	S-HIGH	8.7	HIGH	8.1	7.8	7.8	7.7

The target level for calcium in the fruit at harvest is greater than 5 mg/100g FW (Smith, 1999). Values greater than 5 mg/100g are likely to have firmer fruit. Nitrogen to calcium (N : Ca) ratio 10:1 is considered ideal (Little and Holmes 2000, p100). Ratios greater than 10:1 increase the risk of soft fruit after storage.

[1.] Ratings for the calcium level and N : Ca ratio in fruit at harvest based on Phosyn analysis results, V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Normal Ca levels in the fruit at harvest are 4.83 to 6.45 mg / 100g FW. Very low levels of calcium (3.5 mg / 100 g FW). Normal ratios in fruit at harvest are 1.99 to 6.3. High N : Ca (> 7) ratios in fruit at harvest increase the risk of soft fruit after storage

Table 6a. Total quantity of **phosphorus** applied during the 60 days and 90 days after full bloom (DAFB) and the total amount applied during the fruit growth period (full bloom to harvest) and the fruitlet analysis for orchards 1 to 6 in the 2002 and 2003 harvest seasons.

Orchard and Harvest Year	November 60 DAFB		FRUITLET 25gram[1]		December 90 DAFB		FRUITLET 55gram[1]		Season total Phosphorus	
	Quantity[2] grams	Seasonal[3] percentage	Phosphorus mg/100g FW	Rating[4]	Quantity[2] grams	Seasonal[3] percentage	Phosphorus mg/100g FW	Rating[4]	Quantity[2] grams	Seasonal[3] percentage
Orchard 1										
2002	788g	60.00%	20.8	S-LOW	1313g	100.00%	14.5	S-LOW	1313g	100%
2003	788g	9.50%	13.6	V-LOW	2191g	26.50%	12.1	LOW	8257g	100%
Orchard 2										
2002	2631g	59.70%	20	LOW	3419g	77.50%	14.6	S-LOW	4409g	100%
2003	2520g	22.30%	15.2	LOW	4350g	38.60%	11.8	LOW	11280g	100%
Orchard 3										
2002	2625g	24.30%	16.5	V-LOW	4725g	43.80%	11.7	V-LOW	10785g	100%
2003	2625g	30.50%	13.3	V-LOW	4470g	51.90%	9.4	V-LOW	8612g	100%
Orchard 4										
2002	none	none	22.7	LOW	none	none	12.4	V-LOW	2450g	100%
2003	none	none	17.5	LOW	none	none	12.3	LOW	none	
Orchard 5										
2002	none	none	19.8	LOW	none	none	13.8	LOW	none	
2003	none	none	14.7	V-LOW	none	none	10.3	V-LOW	5480g	100%
Orchard 6										
2002	1173g	11.10%	19.6	S-LOW	3610g	34.10%	13.3	LOW	10592g	100%
2003	2205g	20.90%	13.6	V-LOW	3675g	34.80%	9.9	LOW	10555g	100%

1. Fruitlet 25 gram and 55 gram were the target weights and the actual fruitlet weights are the average fruitlet weights as measured for each orchard.
2. Quantity grams = the accumulated total amount of phosphorus applied in the 60 DAFB, 90 DAFB and the total amount applied during the season.
3. Seasonal percentage = the accumulated percentage of the total amount of phosphorus applied during the fruit growth period (flowering to harvest) for phosphorus.
4. Ratings for the phosphorus level in fruitlets at the 25 gram and 55 gram stages, as set by the Phosyn analysis standards are V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Low phosphorus levels in fruitlets increase the risk of soft fruit after storage. The actual low value is Phosyn's confidential information.

Table 6b. Total quantity of **phosphorus** applied during the 60 days and 90 days after full bloom (DAFB) and the total amount applied during the fruit growth period (full bloom to harvest) and the fruitlet analysis for orchards 7 to 12 in the 2002 and 2003 harvest seasons.

Orchard and Harvest Year	November 60 DAFB		FRUITLET 25gram[1]		December 90 DAFB		FRUITLET 55gram[1]		Season total Phosphorus	
	Quantity[2] grams	Seasonal[3] percentage	Phosphorus mg/100g FW	Rating[4]	Quantity[2] grams	Seasonal[3] percentage	Phosphorus mg/100g FW	Rating[4]	Quantity[2] grams	Seasonal[3] percentage
Orchard 7										
2002	2631g	59.7%	19	LOW	3419g	77.5%	13.5	LOW	4409g	100%
2003	2520g	22.3%	16.9	LOW	4350g	38.6%	11.6	LOW	11280g	100%
Orchard 8										
2002	2631g	59.7%	21.2	LOW	3419g	77.5%	14.7	LOW	4409g	100%
2003	2520g	22.3%	15.5	LOW	4350g	38.6%	11.7	LOW	11280g	100%
Orchard 9										
2002	1050g	23.5%	16.6	V-LOW	3150g	70.5%	13.5	LOW	4470g	100%
2003	3150g	23.90%	11.8	V-LOW	5250g	39.9%	11.8	LOW	13170g	100%
Orchard 10										
2002	1213g	53.6%	17.6	V-LOW	1738g	76.76%	12.4	V-LOW	2264g	100%
2003	3317g	30.0%	13.6	V-LOW	5771g	52.3%	11.6	LOW	11039g	100%
Orchard 11										
2002	none	none	19.8	LOW	none	none	12.9	LOW	none	
2003	none	none	13.2	V-LOW	none	none	10.5	LOW	5480g	100%
Orchard 12										
2002	487g	15.9%	18.2	LOW	1552g	50.7%	13.4	LOW	3064g	100%
2003	698g	18.1%	14.6	LOW	2094g	54.4%	9.8	V-LOW	3850g	100%

1. Fruitlet 25 gram and 55 gram were the target weights and the actual fruitlet weights are the average fruitlet weights as measured for each orchard.
2. Quantity grams = the accumulated total amount of phosphorus applied in the 60 DAFB, 90 DAFB and the total amount applied during the season.
3. Seasonal percentage = the accumulated percentage of the total amount of phosphorus applied during the fruit growth period (flowering to harvest) for phosphorus.
4. Ratings for the phosphorus level in fruitlets at the 25 gram and 55 gram stages, as set by the Phosyn analysis standards are V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Low phosphorus levels in fruitlets increase the risk of soft fruit after storage. The actual low value is Phosyn's confidential information.

Table 7a. **Phosphorus** (fresh weight analysis) for fruit from the 1st harvest and 2nd harvests for orchards 1 to 6 in 2002 and 2003 harvests and the firmness at harvest and after 6 months controlled atmosphere (CA) storage.

Orchard and Harvest year	Mineral levels				Firmness kgf			
	Phosphorus mg/100g FW 1st pick	Rating[1]	Phosphorus mg/100g FW 2nd pick	Rating	HARVEST 1st pick	HARVEST 2nd pick	After CA storage (6 months) 1st pick	After CA storage (6 months) 2nd pick
Orchard 1								
2002	11.8	S-HIGH	10.9	NORMAL	10.2	9.2	8.3	7.4
2003	11.7	S-HIGH	10.9	NORMAL	7.8	7.6	7.5	7.2
Orchard 2								
2002	10.0	NORMAL	9.3	S-LOW	10.3	8.8	8.2	7.5
2003	9.0	S-LOW	7.9	LOW	8.2	7.8	7.6	7.0
Orchard 3								
2002	10.1	NORMAL	8.4	S-LOW	10.1	9.4	8.7	7.3
2003	10.2	NORMAL	9.1	S-LOW	8.3	7.2	7.8	7.3
Orchard 4								
2002	10.9	NORMAL	10.3	NORMAL	9.4	8.1	7.7	6.8
2003	9.5	S-LOW	10.2	NORMAL	8.4	8.4	7.8	7.5
Orchard 5								
2002	9.9	S-LOW	9.3	S-LOW	10.0	8.8	7.9	7.1
2003	9.9	S-LOW	9.1	S-LOW	7.2	6.9	6.8	6.8
Orchard 6								
2002	12.3	S-HIGH	11.9	S-HIGH	8.6	8.2	7.4	6.9
2003	11.1	NORMAL	11.9	S-HIGH	8.1	7.7	7.8	7.3

The target level for phosphorus in the fruit at harvest is greater than 10 mg/100g FW (Smith, 1999).
Values greater than 10 mg/100g are likely to have firmer fruit than fruit with less than 10 mg/100g.

[1.] Ratings for the phosphorus level in fruit at harvest based on Phosyn analysis results, V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Normal P levels in the fruit at harvest are 10 to 11.4 mg / 100g FW. Low phosphorus levels of 8 mg / 100 g. FW in fruit at harvest will increase the risk of soft fruit after storage.

Table 7b. **Phosphorus** (fresh weight analysis) of fruit sampled at the 25 gram and 55 gram fruitlets and fruit from the 1st harvest and 2nd harvests for orchards 7 to 12 in 2002 and 2003 harvests and the firmness after 6 months controlled atmosphere (CA) storage.

Orchard and Harvest year	Mineral levels				Firmness kgf			
	Phosphorus mg/100g FW 1st pick	Rating[1]	Phosphorus mg/100g FW 2nd pick	Rating	HARVEST 1st pick	HARVEST 2nd pick	After CA storage (6 months) 1st pick	After CA storage (6 months) 2nd pick
Orchard 7								
2002	7.9	LOW	9.6	S-LOW	9.8	8.5	8.3	7.3
2003	8.0	LOW	7.7	LOW	8.4	8.2	8.1	7.8
Orchard 8								
2002	11.2	NORMAL	12.1	S-HIGH	10.7	8.8	8.0	7.6
2003	10.0	NORMAL	9.9	S-LOW	8.2	8.1	7.9	7.8
Orchard 9								
2002	11.3	NORMAL	9.8	S-LOW	10.2	8.9	8.3	7.6
2003	10.2	NORMAL	10.4	NORMAL	8.0	7.9	8.0	7.7
Orchard 10								
2002	10.7	NORMAL	10.2	NORMAL	10.1	9.2	7.9	7.5
2003	10.0	NORMAL	10.7	NORMAL	8.1	7.9	7.9	7.8
Orchard 11								
2002	8.8	S-LOW	9.3	S-LOW	9.9	8.8	8.2	7.3
2003	10.4	NORMAL	10.7	NORMAL	7.4	7.7	7.7	7.4
Orchard 12								
2002	10.1	NORMAL	8.9	S-LOW	9.4	8.9	7.3	6.8
2003	10.2	NORMAL	8.7	S-LOW	8.1	7.8	7.8	7.7

The target level for phosphorus in the fruit at harvest is greater than 10 mg/100g FW (Smith, 1999).
Values greater than 10 mg/100g are likely to have firmer fruit than fruit with less than 10 mg/100g.
1. Ratings for the phosphorus level in fruit at harvest based on Phosyn analysis results, V-LOW = Very low, S-LOW = Slightly low, LOW, NORMAL, S-HIGH = slightly high, V-High = very high. Normal P levels in the fruit at harvest are 10 to 11.4 mg / 100g FW. Low phosphorus levels of 8 mg / 100 g FW in fruit at harvest will increase the risk of soft fruit after storage.

8.3 <u>Effect of post harvest calcium dipping on Pink Lady apple firmness.</u>

INTRODUCTION

Post-harvest dipping of apples with calcium solutions can maintain firmness during storage. Foliar application of calcium pre-harvest is expensive. It was proposed that calcium dipping may be a cheaper and equally effective means of getting calcium into the fruit to improve fruit firmness during storage and marketing.

8.3.1 EXPERIMENTAL OBJECTIVES

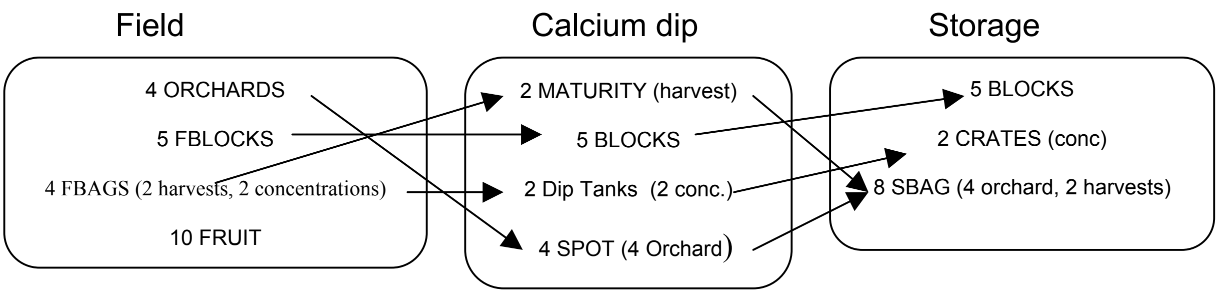
To determine the effect of prestorage calcium dips on Pink Lady apple firmness after storage.

8.3.2 MATERIALS AND METHODS

Pink Lady apples were harvested on the 13th April (pick 1) and on 26th/27th April (pick 2) from six orchards in the Goulburn Valley. Handling was as described for the DPI, storage experiment 2001 (Section 7.2.2). The fruit was stored at 0°C until the 2nd May, then warmed to 20°C and calcium dipped. The control fruit were also warmed but were not calcium dipped. The calcium treatment was 'Stopit' 16% w/v (160g/L) calcium (Ca) as calcium chloride, at the rate of 1.35 litres of product per 100 litres of water. The dipped fruit was allowed to drain then the calcium treated fruit and the fruit not treated with calcium were held at 4°C for 24 hours before being transferred back to 0°C, air storage. On the 8th May, the fruit were transferred from air storage to CA storage (2.5% O_2 plus 2%$_2$). The fruit firmness was measured after 24 weeks storage plus 1 day at 20°C.

Experimental design and statistical analysis

Figure 1. Diagram showing the three phases of the experimental design: Field, calcium dip and Storage.



Letter codes were used to differentiate the phases for analysis.
F = field (example FBLOCK = field block)

8.3.3 RESULTS

In 2001, there was no significant effect of dipping fruit in 'Stopit' on the firmness of first picked fruit after 8 months storage for all orchards (Tables 1). Orchard 5 and 6 fruit from picked 2nd were significantly softer when calcium dipped (Table 2). There was no significant effect of dipping fruit in 'Stopit' for orchards 1,2,3 and 4.

8.3.4 TABLES

Table 1. Effect of calcium dipping with 'Stopit' at 1.35 litres of product (ai 16% $CaCl_2$) 100 litres of water, on firmness of 1st pick fruit after 8 months CA storage plus 1 day at 20°C.

Calcium dip	Orchard					
	1	2	3	4	5	6
minus	7.9	7.3	6.8	7.8	7.3	7.7
plus	8.1	7.2	6.8	7.9	7.2	7.9
LSD (*P=0.05*)[1]	0.2[2]					

[1] Least significant difference of the means (5% level).
[2] Comparing means across rows only. Note there is no significant difference between treatments.

Table 2. Effect of calcium dipping with 'Stopit' at 1.35 litres of product (ai 16% $CaCl_2$) per 100 litres of water, on firmness of 2nd pick fruit after 8 months CA storage plus 1 day at 20°C

Calcium dip	Orchard					
	1	2	3	4	5	6
minus	7.1	6.9	6.6	7.1	6.8	6.7
plus	7.1	6.9	6.5	7.0	6.5	6.3
LSD (*P=0.05*)[1]	0.1[2]					

[1] Least significant difference of the means (5% level).
[2] Comparing means across rows only. Note there is no significant difference between treatments.

9. EFFECT OF CROP LOAD AND TREE VIGOUR ON PINK LADY APPLE FIRMNESS.

INTRODUCTION

Large fruit tend to be softer than smaller fruit (Blanpied et al. 1978). However, Johnson found that early thinning during cell division that is between 5 and 15 days after full bloom results in larger fruit that are firmer (Johnson, 1992). Therefore, it may be an over-simplification to focus on fruit size in relation to fruit firmness.

Fruit with large cells and larger intercellular spaces are generally considered to have weaker tissue than fruits with smaller cells and smaller intercellular spaces (Harker et al. 1997).

The influence of crop load on firmness cannot be solely explained by difference in fruit size. Firmness is generally higher in fruit from low crop loads. The time that trees are thinned can also have an influence on firmness (Harker et al. 2000)

Crop load is a major factor in the evenness of maturity. Light crops differ markedly in maturity and storage potential (Penn State College of Agricultural Sciences, 2003).

Tree vigour is related to tree pruning and rootstocks. If the tree canopy is too vigorous, the vegetative growth will draw nutrients away from the fruit and over-shading will result, which will lead to fruit colouring problems, which in turn will result in the fruit being harvested over-mature which can result in softer fruit.

In this project crop load and tree vigour was measured at each orchard. The effects of crop load and tree vigour on Pink Lady apple firmness are presented as follows.

9.1 EXPERIMENTAL OBJECTIVES

To determine if there were major differences in crop load and tree vigour between orchards and whether this affected fruit firmness after storage.

9.1.2 MATERIALS AND METHODS

Season 2001
On the 18th January 2001 the crop load of trees from six orchards in the Goulburn Valley was measured after completion of hand thinning. Crop load is the number of fruit per tree divided by the butt circumference. Five trees were measured and the crop loads were averaged to give an estimate of the orchard crop load.

Crop load scoring for Pink Lady (Colin Little). Total number of fruit on the tree divided by the butt circumference.1-2 = very light, 2-4 light crop, 4-6 light to moderate crop, 6-8 moderate crop, 8-10 moderate to optimal, 10 –12 optimal for maximum term storage and >12 too heavy (Possible size reduction and risk of reduced return crop unless Nitrogen, Boron, Magnesium, Zinc and Phosphorus is applied as a foliar immediately post harvest and again at green tip).

No tree vigour was measured in 2001 season.

Season 2002
On the 14th and 15th January 2001 the crop load of trees from six orchards in the Goulburn Valley was measured after completion of hand thinning.

Tree vigour was measured on the 6th December 2001 and was recorded as the average length of five new terminal shoots (Plate 1).

Season 2003
Due to drought and severe heat conditions in the Goulburn Valley in the period 26 December to 28 February, most orchards reduced crop loads by a second hand thinning during January. On January 13th and 14th the crop loads were measured.

Tree vigour was measured on the 17th to 18th December 2002. Five new shoots were measured on five trees to give an estimate of orchard tree vigour. There are no standards for this type of measurement.

9.1.3 RESULTS

Season 2001

Crop load
In 2001, there was a large range of crop loads between orchards. Orchards 1, 4 and 12 were carrying optimum crop loads for long term storage (Table 1). Orchards 3 and 5 were carrying moderate to optimal crop loads and orchard 2 had a moderate crop load.

Tree vigour
Tree vigour was not measured in 2001 season. However, there was considerable variation in the tree canopy density between orchards as demonstrated for orchards 4 and 6 (Plate 2).

Season 2002

Crop load
In 2002, orchards 6 and 10 had optimum crop loads for long term storage, orchards 4, 5, 7 and 12 had moderate crop loads and orchards 1, 2 and 3 had light to moderate crop loads (Table 1).

Tree vigour
Orchards 1, 2, 3, 5, 8, 9, 10, 11 and 12 had similar new shoot growth and the trees were fairly well settled-down. Orchard 4 was treated with Cultar® a growth retardant which reduced tree vigour. Orchards 6 and 7 had excessive growth (Table 2). It was observed that orchards 4, 5 and 7 had the poorest fruit red colour development.

Season 2003

Crop load
In 2003, orchards 1, 10 and 11 had optimum crop loads for long term storage, orchards 5, 6 and 12 had moderate crop loads, orchards 2,8,9, and 11 had light to moderate crop loads and 3 and 7 had light crop loads (Table 1).

Tree Vigour
In a drought year, new shoot growth was generally less than the previous year. Orchards 6 and 7 growth had reduced vigour compared to the 2002 season growth (Table 2).

9.1.4 TABLES

Table 1. Crop loads recorded after completion of hand thinning for twelve orchards in the Goulburn Valley for seasons 2001, 2002 and 2003.

Orchard	Crop load (fruit per centimeter butt)		
	2001	2002	2003
1	9.6	11.4	4.4
2	6.5	3.1	5.6
3	8.8	2.2	5.9
4	10.2	7.8	6.1
5	9.5	6.1	6.2
6	12.1	6.2	10.5
7	-	2.1	6.2
8	-	3.5	9.8
9	-	3.6	13.0
10	-	11.5	11.2
11	-	4.5	11.2
12	-	6.2	7.7

1-2 = totally off, 2-4 light crop, 4-6 light to moderate, 6-8 moderate crop, 8-10 moderate to optimum, 10-12 optimum for maximum term storage, >12 too heavy.
Orchards 7 to 12 were not part of the project in season 2001.

Table 2. Tree vigour recorded after completion of hand thinning for twelve orchards in the Goulburn Valley for seasons 2002 and 2003.

Orchard	Tree vigour Average new shoot growth (cm)	
	2002	2003
1	27.9	19.1
2	32.4	31.8
3	24.8	17.6
4	14.8	24.2
5	24.3	19.3
6	45.9	33.4
7	43.0	18.9
8	21.4	19.8
9	32.9	14.8
10	32.6	5.7
11	29.6	27.3
12	31.2	26.4

Shoot growth was not measured in season 2001.

9.2.4 PLATES

Plate 1. Colin Little and Glenn Hale measuring tree vigour.

Plate 2. In 2001 the canopy density and tree vigour were variable between orchards. Orchard 4 (left) had a good open tree structure allowing good light penetration compared to a dense tree structure for orchard 6.

10. WEATHER

10.1 Weather literature review

Many studies have described how apple firmness can vary between seasons, between orchards and between regions (Knee and Smith, 1989, Watkins, 1993). Weather conditions at blossom time affect the uniformity of maturity within the tree. Most pome fruit mature with better quality if the maximum daytime temperatures are not too extreme (Little and Holmes 2000, p104). Wide variations between daytime maximum and night time minimum with many sunshine hours favour even maturation, high sugar levels, excellent red colour development and good storage characteristics (Little and Holmes 2000, p106). Changing temperatures, rainfall patterns and dull weather tend to favour wider variability and non-uniform maturity within a tree canopy. Flowering can occur over several weeks' especially during cooler weather favouring variable maturity at harvest.

Stanley et al. (2000) reported that the potential maximum fruit size is set by about 50 days after pollenation (DAP) and this is determined by total cell fruit number, resulting from a temperature – responsive cell division growth phase. There are suggestions that higher temperatures shorten the cell division phase, giving the fruit fewer, larger cells.
After the period of cell division there is a second phase of cell expansion that is also temperature dependent. Warrington et al. (1999) found that fruit expansion rates were highly responsive to temperature. Temperatures in the period from 30 to 40 days after full bloom (DAFB) are most critical in determining harvest maturity (Warrington et al. 1999). Cell size and number directly influence fruit firmness at harvest. Warrington concluded that cell size and number directly influenced fruit firmness. This is consistent with the observation that increased cell division, stimulated by the application of benzyladenine, resulted in enhanced firmness (Wismer et al. 1995).

The vegetative phase has finished by mid-December in the Goulburn Valley when cell division has ceased (Little and Holmes 2000, p.62).

A number of studies have shown a strong positive correlation between temperatures immediately following bloom in the field and fruit size at harvest (Warrington et al. 1999). The apple fruit grows in two district phases: an exponential phase of cell division that typically lasts for approximately 35 to 45 days after anthesis, followed by a expansion phase for the remainder of the season until commercial maturity.

The time that fruit reach optimum harvest maturity in commercial apple orchards can be influenced by a number of factors including bloom date and the climate, for example temperature, that prevail during fruit development. Some studies have determined a high correlation between accumulated heat units and the time interval between bloom and optimum harvest. Kronenburg (1988) found that the conditions prevailing during the first month after flowering had the greatest impact on harvest date. Warrington et al. (1999) found that starch index was higher (ie starch hydrolysis was more advanced), flesh firmness lower, and background colour more yellow under warmer than under cooler maximum/minimum temperature conditions.

In apples ripening proceeds faster when days are relatively warm and nights are cool. (Little and Holmes 2000, p121).

The effects of weather conditions on Pink Lady apple firmness after CA storage are discussed below.

10.2 Effect of weather on Pink Lady apple firmness

10.2.1 EXPERIMENTAL OBJECTIVES

Determine if the temperature variation between the orchards was a major factor affecting the difference in firmness.

10.2.2 MATERIALS AND METHODS

A weather station was located at each orchard (Plate1). The stations were located mid-way between two trees on the dripper line. Each station consisted of a Hobo® temperature logger mounted under a rain cover cap positioned 1.2 meters off the ground. Accumulated degree days (ADD) were calculated for each orchard. Temperature was recorded hourly. Averages were calculated for every two hours and the sum of the averages for the full bloom to harvest time was divided by 24 to give ADD.

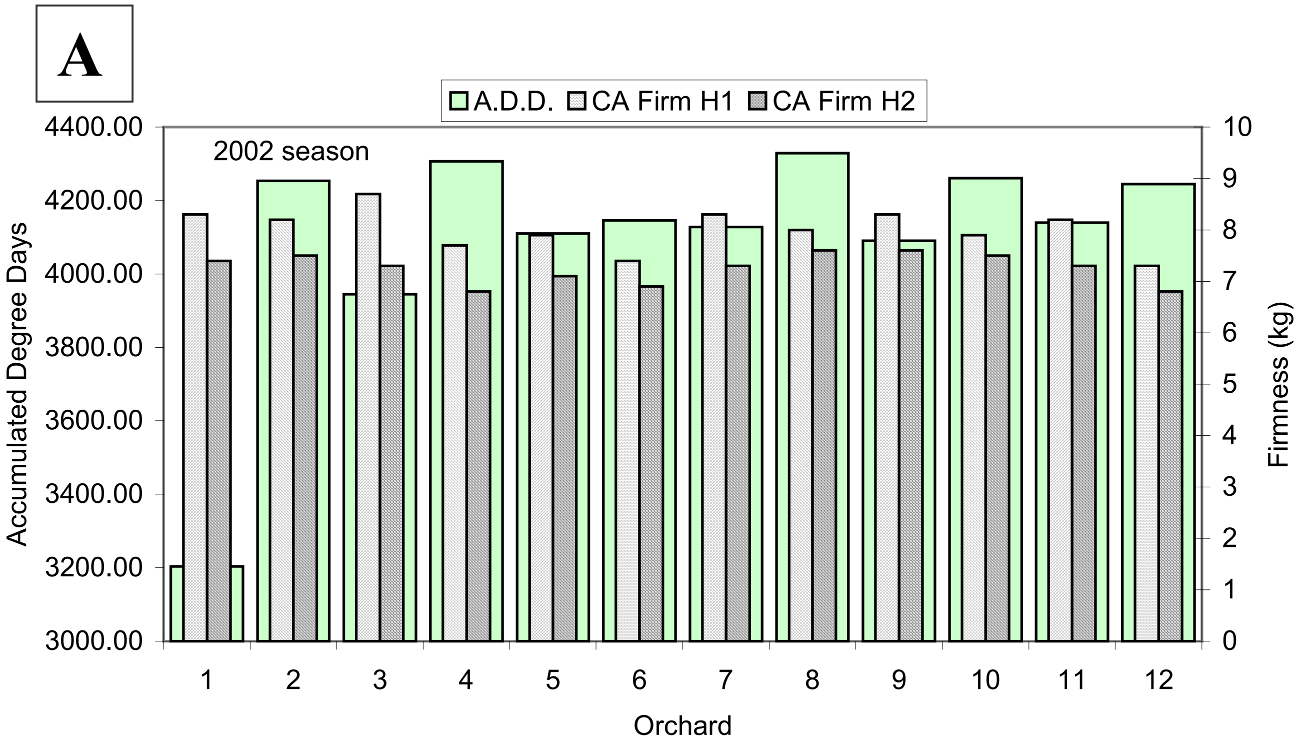
Plate 1. The weather station used at each orchard.

10.2.3 RESULTS AND DISCUSSION

In general, the temperature variation between orchards as quantified by accumulated degree days was small (Figures 1a and 1b). Where there were substantial differences such as orchard 1 in 2002 and orchard 9 in 2003 the lower ADD values did not appear to affect the firmness of the fruit after long term CA storage in comparison with the other orchards.

The weather stations used in this project were not housed in a Stevenson's screen. This has most likely resulted in higher ADD values than would have been achieved in a Stevenson's screen. A comparison of data collected at the Tatura Met station which used a Stevenson's screen and orchard 3 which was less than 0.5 kilometer away indicated this (Fig. 2). Therefore the ADD serve as a relative comparison of temperature variation between orchards not an absolute value.

10.2.4 FIGURES



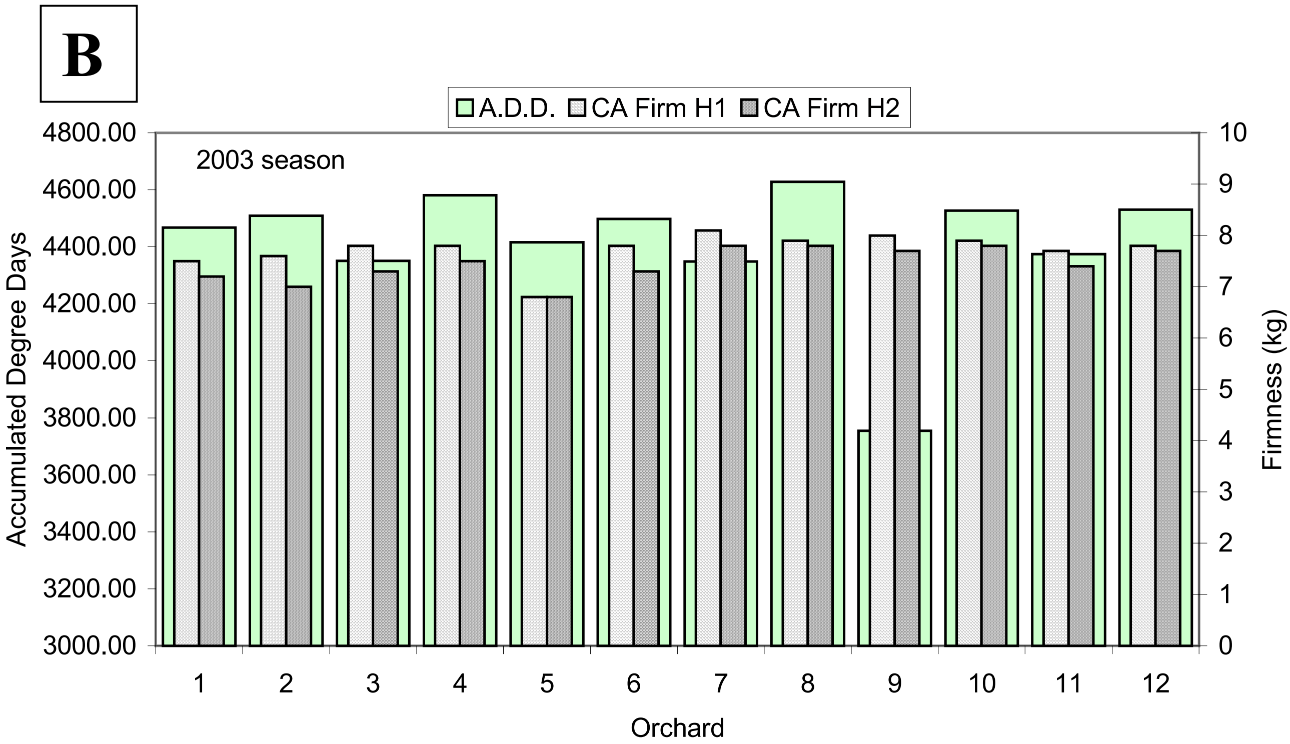


Figure 1. A comparison of the accumulated degree days (ADD) at each orchard during the full bloom to harvest period with the firmness of apples from the 1st and 2nd harvests, after 6 months CA storage for the 2002 (A) and 2003 (B) seasons.

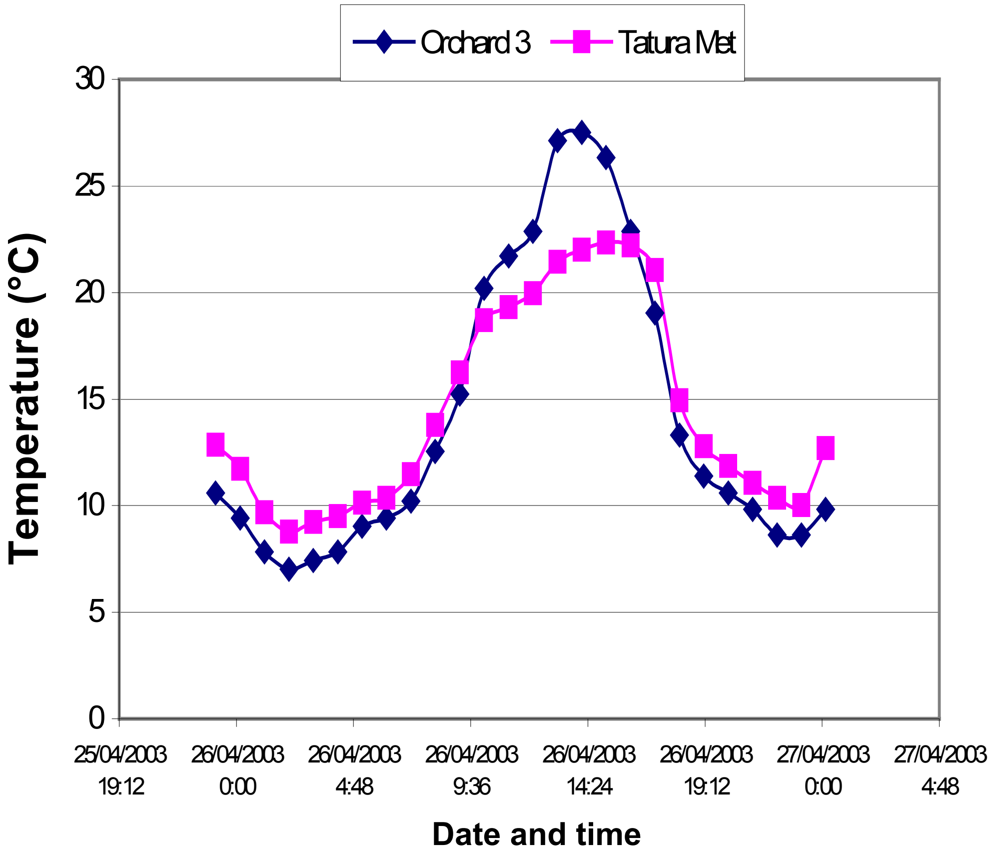


Figure 2. Temperature profiles for data collected at the Tatura Met station (in a Stevenson's screen) and data from orchard 3 (no Stevenson's screen, see Plate 1).

11. ROOTSTOCK AND GROWTH RETARDATION METHODS EFFECTS ON FIRMNESS AND INTERNAL BROWNING

11.1 Literature review

The major purposes of rootstocks for apples are to control tree size, induce precocity, improve yield, provide soil adaptation and combat various soil-borne pests and diseases (Elfving, 1987). Castle, 1995 published an excellent review entitled " Rootstocks as a factor in citrus and deciduous tree crop". In the review, apple rootstocks are purported to affect fruit quality, but much of the work is criticised because of a limited number of rootstocks, too few years of study and failing to account for confounding factors such as crop load, canopy management and environmental factors (Autio 1987, 1991).

Red colour development of Pink Lady apples in the Goulburn Valley can be a problem for some growers. The market demands in 2001 was for Pink Lady apples to have 60% blush. This meant for some orchards the maturity at harvest was well past optimum maturity for long term storage (export). In 2004, the colour specification for Pink Lady apples on the domestic market was lowered in line with the export specification of 45 to 50% blush.

Red colour is based on the amount of the plant pigment called 'anthocyanins'. Good red colour depends on degradation of chlorophyll and increase in anthocyanins (Kupferman, 2002b).

The critical colouring period is two to three weeks before harvest. The optimum temperature for red colour formation varies among cultivars but generally between 20° - 25°C with cool night temperatures less than 18°C (Gurnsey and Lawes, 1999). However, if cool night temperatures, are followed by excessive (greater than 30°C) daytime temperatures, the positive effects on anthocyanin synthesis will be negated. Light levels are also an important factor in anthocyanin synthesis. Apples require a minimum of 50 % full sunlight on fruits and leaves in order to achieve adequate red colour. Pink Lady requires both cold and warmth with high sunshine hours as fruit approaches harvest.

Seniphos (Phosyn) is a mineral mixture (high in phosphorus) which is applied 2-3 weeks before commercial harvest. Seniphos may improve colour in apples by increasing the activity of phenylalanine-ammonia-lyase enzyme (PAL) which is a determining factor of colour enhancement (Larrigaudiere et al. 1996). Seniphos helps to increase fruit phosphorus level that may enhance colour development and firmness.

Reflective mulches placed on the ground between tree rows have been used to increase red colour. Products like Extenday improve fruit colour by increasing light interception and distribution back into the tree. Similarly, spray on reflective blankets called Sun-Brite can double the amount of light penetration into the tree canopy.

Regalis (prohexadione-Ca) is a growth regulator for use on pome fruit crops. It inhibits the growth hormone gibberellins (Roemmelt et al. 2003). As a result longitudinal shoot growth is reduced.

Internal browning also referred to as flesh browning is sporadic in nature and occurs in air and CA storage. The disorder seems to be the result of a combination of factors that have been implicated in other storage disorders of apples.

Internal browning was observed at DPI, Knoxfield in 2000 when assessing fruit as part of the Victorian State Government export initiative project Apple ExpHort 2000. In 2000, the symptoms were senescent-like, refereed to as FB type one (see Section 11.3.2 Plate 1a). In 2001, apples were shipped to the UK, where again FB-type 1 was observed but only in a few growers' fruit. As fruit from the 6 growers were stored in the same CA tent (2.5% O_2 plus 1% CO_2) this result suggests that the fruit are pre-conditioned to the disorder prior to storage. In 2002, the fruit had a different type of browning radial-like, refereed to as FB-type 2 (see Section 11.2.3 Plate 1b). Fruit from 12 orchards in the Goulburn Valley were treated with or without the ethylene action inhibitor SmartFresh™ at harvest and stored for 6 months in CA. When the fruit was assessed for FB some growers' fruit had severe FB-type 2 while other had none. A severity rating scale was created and used to assess the fruit (see Section 11.2.2 Plate 2). There was no significant effect of SmartFresh™ on the incidence and severity of FB-type2.

Flesh browning occurs in more mature Pink Lady apples on fruit trees with high nitrogen and low calcium levels. When the crop load is heavy and there is a large temperature differential at harvest between day and night, the risk of the disorder increases (Kupferman, 2002).

In 2000, Dr Gordon Brown submitted a proposal to Horticulture Australia Limited to investigate the effects of seasonality, rootstocks, maturity, and growth control methods on the storage life and flesh browning of Pink Lady apples. HAL made a decision to incorporate Gordon's proposal into the 'Tracking Pink Lady apple firmness project AP 01036' (see Section 11.2).

11.2 Minimising internal browning in Pink Lady apples- Scientific Horticulture project

Gordon S. Brown, Lisa J. Schimanski and David Jennings

Summary

The 'Pink Lady' cultivar was bred in Australia and released in 1991. The first known occurrence of internal browning of controlled atmosphere (CA) stored fruit was recognised in September 2000. It first appeared in Tasmania, and has since also been recognised in many other regions of Australia and overseas (New Zealand, France, Italy, United Kingdom, U.S.A, and South America). The problem appears to be region and grower specific. The economic effects of internal browning in 'Pink Lady' apples not only result in direct losses incurred by post-harvest operators and marketers, but also the flow-on effects of loss of market confidence, and hence lower prices for the commodity, both nationally and internationally.

A survey conducted by the authors in 2001 identified that fruit with internal browning was more often associated with orchards on dwarfing rootstocks and/or with severe growth control practices. There was also a suggestion that fruit maturity may be important. The aim of the research reported here was to ascertain the validity of these associations.

The results of this research showed that, i) seasonal variations strongly influence the incidence of internal browning in Tasmanian 'Pink Lady' apples; ii) the more dwarfing the rootstock, the greater the incidence of internal browning and although, rootstock does not affect fruit quality at harvest; there are indications that it will influence fruit metabolism; iii) the occurrence of root disease increases the incidence of internal browning in the fruit; iv) maturity is a key factor in the expression of the disorder, suggesting that this is a form of senescent breakdown.

Introduction

There are two major types of internal browning in 'Pink Lady' apples; diffuse and radial browning. Diffuse internal browning in 'Pink Lady' apples is located in the outer cortex of the fruit flesh, and initially the symptoms appeared as a slight grey colour that is barely visible. Radial internal browning occurs along the vascular traces radiating out from the cortex. Discolouration of the fruit flesh occurs in other apple cultivars, such as 'Braeburn' apples, where browning is the result of elevated CO_2 in the flesh of the fruit, this may be associated with the high fruit density and skin resistance (Rajapakse *et al.* 1990). Sensitivity to high CO_2 also causes flesh discolouration in 'Fuji' apples (Volz *et al*. 1998). However, in Tasmania the discolouration noted in the 'Pink Lady' cultivar was not in the core region, and was not associated with high CO_2 levels in storage indicating that this was not CO_2 injury during storage. The symptoms were also inconsistent with other commonly encountered forms of internal breakdown.

An extensive survey of fruit quality, storage conditions and orchard practices was conducted by Brown and Schimanski (2001) on 13 lines of Tasmanian 'Pink Lady' apples, and four lines of fruit from Western Australian orchards. This survey identified that affected fruit tended to; (i) be stored at lower CO_2 and O_2 levels (1.3% CO_2 and 2.0% O_2) than unaffected fruit (2.0% CO_2 and 2.5% O_2), (ii) have a higher firmness, (iii) be higher in zinc (commonly due to foliar zinc sprays), (iv) originated from dwarfing rootstocks, (v) were from trees where active growth control, such as cincturing and summer pruning, were practised.

Rootstocks have been noted to have a large influence on fruit quality in other cultivars. For example, 'Granny Smith' apples on M26 (dwarfing) rootstocks produce fruit with a high firmness, soluble solids (TSS), Calcium content and early maturity, conversely this cultivar was greener on M111 and seedling (Drake *et al.* 1991).

The aim of this investigation was to provide industry with some tools to reduce the incidence of internal browning for long stored fruit, by identifying the effect of seasonality, rootstock, root disease, maturity, and growth control methods on the incidence of internal browning.

Method

Seasonality

An assessment of the incidence of internal browning on an annual basis has been conducted from 1999-2003. These values were calculated on the average of internal browning for several growers through southern Tasmania.

Rootstocks trial

Season 2001

Trial site - This trial was conducted at the Grove Research Station in the Huon Valley of Tasmania (Australia) on five year old trees that were grafted as single tree plots, onto 'MM106', 'MM106/9' interstem, 'M26' and 'Ottawa 3' abbreviation 'O3'. Rootstock abbreviation are Merton Malling 'MM' series and the Malling series 'M'. The trial was composed of 8 replicates in a randomised complete block design, although due to root disease the trial was reduced to 5 replicates.

Harvest assessments - Approximately 50 fruit per plot were harvested 1 week prior to commercial harvest, at commercial harvest (23 April 2001) and 1 week after commercial harvest. At harvest, three fruit from each plot were pooled by rootstock and assessed for weight, firmness, total soluble solids (TSS) and starch. Firmness was measured using a computer controlled fruit penetrometer (11 mm probe, skin removed) which also measured diameter and obtained a sample of juice for the analysis of TSS. TSS was assessed using a digital refractometer. Starch was measured by cutting the fruit in half transversely and placing one cut side face down in iodine for approximately 10 seconds. The percentage of starch blackening was visually assessed and random samples verified with image analysis. At the time of final harvest, the unharvested fruit were counted and the trunk cross sectional areas measured. The results for each harvest were averaged across the rootstocks.

Storage assessments - The fruit were stored at 0.5° C in air until the final harvest, then placed in a commercial controlled atmosphere (CA) storeroom (1.0% CO_2, 2.2% O_2 and 0.5° C). After four months, the fruit were removed and placed into a 5° C refrigerated container for seven weeks to simulate poor shipping conditions to Europe. Twenty fruit from each plot were assessed for weight, firmness, diameter, TSS (all measured as described above) and internal CO_2 and O_2. Internal CO_2 and O_2 were assessed by placing a hypodermic needle into the cavity of the apple and withdrawing a 1 ml sample of air. This air was pooled from all 20 fruit per plot and then injected through a modified Besseling Agri-technic B.V. portable duo O_2 and CO_2 analyzer to determine the internal cavity concentrations of these gases. All fruit were assessed for greasiness and internal browning. Greasiness was assessed by feeling the fruit and scoring the level of greasiness on a scale of 0-5, with 0 not being greasy and 5 being extremely greasy. A value over 3 would be considered unmarketable. To assess for internal browning the fruit were cut transversely and any incidence of browning was recorded. The data was analysed using a split plot in time statistical analysis method. The average of all three harvest dates was taken to obtain values for the parameters measured.

Season 2002

Trial site - This trial was conducted at the Grove Research station in the Huon Valley of Tasmania (Australia) on 10 year old trees that were grafted onto 'MM106', 'MM106/27'

interstem, 'MM106/9' interstem, in 3 tree plots, replicated 6 times in a randomised complete block design.
Harvest assessments - Approximately 80 fruit (1 loose pack box) per plot were harvested at 10 days prior to commercial harvest, commercial harvest (19/04/02), and 10 days after commercial harvest. At harvest three fruit from each plot were pooled by rootstock and assessed for weight, firmness, total soluble solids (TSS) and starch (as described previously).
Storage assessments - The fruit were placed in a commercial CA storeroom for seven months, and then transferred to a refrigerated container for five weeks to simulate transport to Europe. Fruit were assessed for weight, firmness, diameter, TSS and internal browning (as described above). The data was analysed using an ANOVA statistical analysis method. The average of all three harvest dates was taken to obtain the values for the parameters measured

Season 2003
Trial site – This trial was conducted at the Lenswood Research station in South Australia on 10 year old trees that were grafted onto 'MM106', 'M7', 'M9', 'M26', 'O3', and 'M102', in 5 tree plots, replicated 4 times in a randomised complete block design.
Harvest assessments – The fruit were monitored on a weekly basis, and each rootstock was picked at the same starch plate of 3.5 on the Ctifl 10 point scale (consistent with fruit going into long term storage). There was a 7-10 day variation from the harvest of the earliest maturing rootstock to the harvest of the latest one. Assessments of firmness, TSS and starch were taken at harvest. Two loose packed boxes of fruit per plot were harvested.
Storage assessments - Fruit were air stored until all the fruit were harvested. One box from each plot was kept in air store, while the other box from each plot was placed in a commercial CA storage facility for 6 months. These fruit were then transported to Tasmania under refrigeration and placed in a refrigerated container for a further three weeks to simulate transport to Europe. A sample of 20 fruit from each plot were assessed for weight, TSS, firmness, diameter and greasiness (as previously described). Additionally, the red surface area of the equatorial peel of ten fruit was determined with image analysis (Optimus 6.1). All fruit were assessed for internal browning.

Root Disease

Season 2001
At the first harvest of the 2001 rootstock trial, a visual assessment (0-10) was made of the general condition of the trees. From this assessment only one tree was noted as being poor, having symptoms consistent with a root disease such as phytophthora, fruit were stored and assessed as per the details outlined above. The following growing season (2001/2002) was unusually wet and during this growing season six trees in the trials site displayed symptoms of severe root disease infection. The incidence of internal browning for trees with severe symptoms of root disease was compared with nearby trees on the same rootstock and analysed using a 'T' test.

Season 2002
A visual assessment (0-10) was made of the general condition of the trees to give an indication of the presence of root diseases and approximately 80 fruit from both affected and healthy trees was harvested. Fruit were stored and assessed in a similar manner to the 2002 rootstock trial. The incidence of internal browning for trees with severe

symptoms of root disease was compared with nearby trees on the same rootstock and analysed using a 'T' test.

Growth regulation trials

Season 2002

This trial was set up in a commercial orchard of vigorous 'Pink Lady' apples in the Huon Valley of Tasmania during the spring of 2001. The trees were approximately 4.5m tall, planted 2m apart in rows 4.8m wide. The trees were on 'MM106/9' rootstocks. Full bloom was on 29 September 2001.

Six treatments were applied in 2001 and replicated 4 times on 3 tree plots. Treatments were; an untreated control, cincturing of the trees (4/10/2001), Regalis® (1/10/2001-12 noon, overcast, breeze, 23°C, 52%RH and 8/11/2001-12 noon, overcast, calm, 21°C, 75%RH at 1.266kg/Ha with an airblast sprayer), a severe summer pruning (28/12/2001 and preharvest deleafing treatment (8/3/2003), reflective cloth (Extenday® 3m wide on each side of plots, 8/3/2003) and Retain® (22/3/2003 – 830g/Ha with hand lance, calm, sunny 20°C).

The shoot lengths of 15 vigorous shoots per plot were measured on the untreated control, Regalis® and Cincturing treatments on 2 November 2001 and 28 December 2001.
Fruit harvest occurred on 24/4/2002. Approximately 60 fruit from each plot were harvested and placed in a box for controlled atmosphere storage. In addition, a sample of 20 fruit per plot was taken to determine harvest maturity. Fruit weight, firmness, TSS, starch, were assessed as per previously described, additionally, the red surface area of an equatorial peel of each fruit was determined with image analysis (Optimus 6.1). The fruit for storage were placed in a commercial controlled atmosphere facility in a room operating at 0.5°C, 1.5% CO_2 and 1.5% O_2. They were removed from storage after 7 months (20/11/2002) and a sample of 20 fruit per plot tested for firmness, TSS and internal browning (as previously described). The remaining fruit were stored in a commercial cold room at 1°C for a further 19 days to simulate normal delays in marketing and then a sample of 20 fruit were assessed for internal browning.

Season 2003

The same trees as used in the 2001/02 trial were used for this seasons trial. The untreated control, cincturing, Regalis®, summer pruning, and reflective cloth treatments were all applied to the same trees as in 2001/02. However, the Retain® treatment was replaced with an Ethrel® treatment and some unutilised trees in 2001/02 were given a chain saw treatment. In this season full bloom occurred on 9 October 2002. The Regalis® was applied on October 10 2002 (11am, sunny and calm, 17°C and 43%RH) and October 29 2002 (12 noon, sunny and calm, 21°C, 40% RH) with an airblast sprayer. The cincturing occurred on October 14 2002, Trees were chain sawed (half way through trunk at 200mm above the ground and again on the other side of the trunk but 100mm higher) on October 29 2002. The trees were summer pruned on January 6 2003 and the reflective cloth was applied on March 24 2003. Ethrel® was applied on 28 March 2003 (300ml/Ha with a hand lance, overcast, 18°C and calm).

On October 10, 2002, visual estimates of the percentage of flowers open and flower density were made. The shoot lengths of 10 vigorous shoots were measured on the untreated control, Regalis®, cinctured, summer pruned and chain sawed treatments on October 9 2002, December 10 2002 and May 26 2003. The Ethrel® treated trees were harvested on April 17 2003 and the remaining trees were harvested a week later on April 24 2004. At each harvest 2 boxes of 84 fruit were collected as well as a sample of 20 fruit for harvest maturity determination (firmness, TSS, starch and percent area of red skin) as determined in the previous season. All fruit were placed in long term CA storage in a commercial facility and were assessed for fruit quality and internal browning (as previously described) on 8 October 2003.

Maturity trials

Season 2001
This trial was conducted in conjunction with the 2001 rootstock trial; refer to this section in the methods for the trial site, harvest assessments and storage assessments. The effect of harvest date was analysed with a split plot in time ANOVA, using LSD to split the means.

Season 2002
This maturity trial was established in conjunction with the growth regulation trial; fruit were harvested at weekly intervals from 6 weeks before commercial harvest and assessed for maturity using the maturity index described below. Additionally, 80 fruit were harvested at 2 weeks before harvest, 1 week before harvest, commercial harvest (22/04/02) and 1 week after harvest. Fruit were than placed in CA storage with the fruit from the growth regulation trial, and assessed in a similar manner.

Maturity Index
From 1998 to 2003 fruit were sampled from a number of orchards within the Huon Valley of Tasmania to ascertain a profile of maturity. Twenty fruit (two from each of 10 trees) were harvested at weekly intervals from 5-6 weeks before commercial harvest to commercial harvest. The fruit were assessed for firmness, TSS and starch as outlined previously. The maturity index was calculated from the following equation

$$MI = \frac{10(\text{Firmness (Kg)} \times \text{TSS (\%)})}{\text{Starch (\%black)}}$$

Results and discussion

Seasonality
This disorder was first observed in 2000, prior to this, internal browning had not been observed in 'Pink Lady' apples, so it can be assumed to be below the 1% market tolerance. In the four seasons when this disorder has been studied, it was at a maximum in 2002; with half of all fruit examined having internal browning, and a minimum in 2003 with less than 5% of fruit examined affected by the disorder (Fig 1.). The fluctuations in the annual levels of the disorder indicate that there is a seasonal component to internal browning. Recent investigations by Schimanski *et al*. (2003) indicate that internal browning in 'Fuji' apples due to treatment with methyl bromide, may be exacerbated by frost events just prior to picking. This is consistent with the results for 'Braeburn' apples, which indicate that internal browning in this cultivar is associated with cool growing season, especially if the fruit are over-mature (Lau 1998). Therefore, the occurrence of frost and sudden

temperature changes requires further investigation in both the 'Fuji' and 'Pink Lady' cultivars.

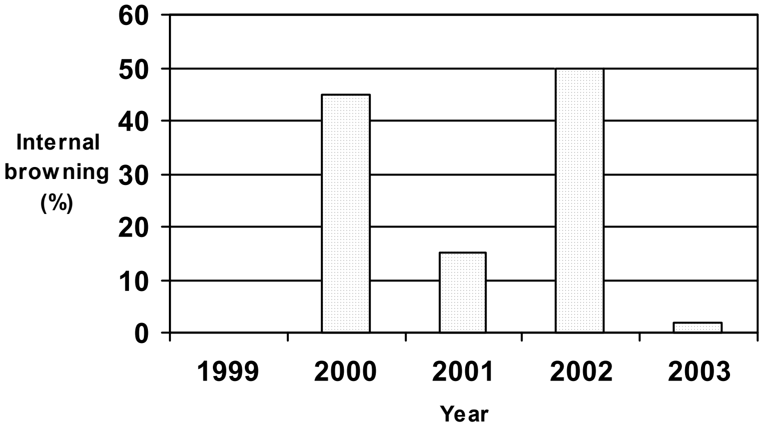


Figure 1. Seasonal change in the incidence of internal browning of Tasmanian 'Pink Lady' apples

Rootstocks

In 2001, the rootstocks all had fruit of a similar maturity, although there was some variation between firmness and starch, these differences were not significant (Table 1). 'Ottawa 3' and M26 had a similar crop load while MM106 had the lightest crop load (Table 1).

Table 1: Fruit quality parameters from various rootstocks at harvest, 2001.*

Rootstock	Firmness	TSS	Starch	Fruit weight	Number of fruit	Trunk tcsa	Yield	Yield
	kg	%	%	g		cm^2	kg/tcsa	#/tcsa
MM106	10.20	16.8	81.7	124	1074	60.1	0.56	7.84
MM106/9	9.88	16.6	71.3	126	1040	37.6	0.77	9.71
M26	9.61	16.3	63.8	133	930	31.9	1.05	10.06
O3	10.41	16.8	79.3	111	602	13.8	0.94	9.03
	n/s	n/s	n/s	n/s	n/s	n/s	n/s	n/s

* Fruit quality parameters averaged across the three harvest dates, n/s = not significant p≥ 0.5

Table 2. Fruit quality parameters from various rootstocks at harvest, 2002.*

Rootstock	Firmness	TSS	Starch	Diameter	Weight	Red	C2H4	Internal O2	CO2
	Kg	%	%	mm	g	%	ppm	%	%
MM106	11.8	12.2	35.0	71.7	155	65.4	0.0	15.6	4.31
MM106/9	11.8	12.2	27.5	71.8	157	64.2	0.3	15.8	4.20
MM106/27	11.5	12.3	25.8	71.2	153	67.1	0.2	15.8	4.18
	n/s	n/s	n/s	n/s	n/s	n/s		n/s	n/s

* Fruit quality parameters averaged across the three harvest dates, n/s = not significant p≥ 0.5

In 2002, the fruit appeared to have very similar levels of firmness, and TSS and a variation of only 10% in starch levels, indicating comparable fruit maturity (Table 2). However, the fruit in 2002 was at least 1 Kg firmer at harvest than fruit from 2001, but with lower levels of TSS and starch (Tables 1 &2). In 2002, the fruit were well above specification (40%) for red colour at harvest (Table 2), and there were no significant differences between ethylene, internal oxygen and internal carbon dioxide across rootstock (Table 2).

In 2001, the incidence of internal browning in ‘Ottawa 3’, the most dwarfing rootstock, was double the other three rootstocks after fruit storage and simulated transport (Fig. 2). In 2002, the incidence of internal browning was higher regardless of rootstock, however, the type of rootstock had an impact, with fruit from the dwarfing combination, ‘MM106/27’ having a higher incidence of internal browning than the other two interstems (Fig. 2). Of interest, is that the crop load of the ‘Ottawa 3’ rootstock, when expressed on a kg/cm^2 of trunk basis, was similar to that of M26, which had the least incidence of internal browning (Table 1, Fig. 2). Further the crop load of MM106 was about half that of M26 and there was no significant difference in the incidence of internal browning (Table 1). This suggests that crop load is not associated with this disorder.

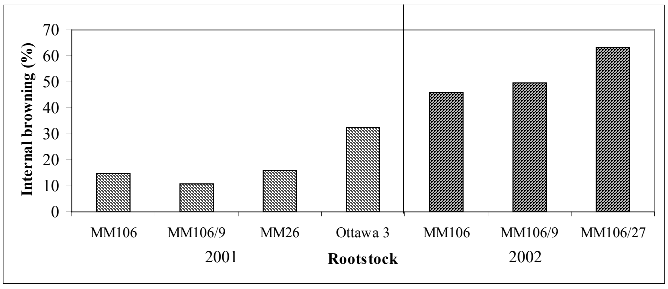


Figure 2. The effect of rootstocks on internal browning of ‘Pink Lady’ apples in 2001 & 2002

After CA storage there was no difference in the firmness or TSS of the fruit across rootstock, in both 2001 and 2002 (Table 3). In 2001, while the incidence of internal browning of ‘Ottawa 3’ was at least double the other three rootstocks after fruit storage and simulated transport, the CO_2 in the internal cavity of the fruit was significantly lower than fruit from ‘MM106/9 and ‘M26’(Table 3). Conversely, O_2 in the internal cavity of the fruit was higher in ‘Ottawa 3’ than the other three cultivars (Table 3). These results are contrary to those shown for 'Braeburn' fruit, where internal browning is the result of elevated CO_2 in the flesh of the fruit. This is often explained by a high resistance to gas diffusion out of the apple core (Rajapakse 1990, Johnston *et al*. 1998). The lower levels of internal CO_2 and greasiness and higher levels of O_2 for ‘Ottawa 3’ indicate that fruit from this rootstock had lower levels of metabolism during storage and simulated transport suggesting that this is not a high CO_2 related disorder. Rootstocks have been noted to have a large influence on fruit quality in other cultivars. For example, ‘Granny Smith’ apples on M26 (dwarfing) rootstocks produce fruit with a high firmness, soluble solids (TSS), Calcium content and early maturity; conversely this cultivar was greener on M111 and seedling (Drake et al 1991).

Overall, neither rootstock nor interstem affected harvest firmness, starch or TSS (Tables 1 and 2) indicating similar fruit maturity, and in both years the severity of internal browning increased as the vigour of the rootstock decreased (Fig. 1). Rootstock did affect the post-storage greasiness, internal CO_2 and internal O_2 of the fruit, indicating that rootstock influences fruit metabolism (Table 3).

2001						2002		
Rootstock	Greasy %	CO_2 %	O_2 %	Firmness Kg	TSS %	Rootstock	Firmness Kg	TSS %
MM106	83.3 ab	1.93 a	18.4 a	6.68	18.3	106	8.94	13.11
MM106/9	90.7 b	2.20 b	18.0 a	6.94	18.8	9/106	8.88	13.01
M26	92.4 b	2.17 b	18.0 a	6.60	18.6	27/106	8.60	12.69
O3	77.1 a	1.77 a	19.0 b	6.95	17.4		n/s	n/s
significance	*	*	*	n/s	n/s		n/s	n/s
LSD[#]	12.4	0.3	0.53					

[@] fruit quality parameters averaged across the three harvest dates. * = significant to $p<0.05$, n/s.= not significant. Note: numbers with the same letters are not significantly different.
[#] LSD = least squared difference

In the 2003 season there was very little internal browning nationally, in South Australia there was no incidence of internal browning (Table 4), therefore no information is available about the effect of either controlled atmosphere or rootstock on the incidence of internal browning. However, there was useful fruit quality data. On average fruit stored in CA were significantly firmer and less greasy than fruit stored in only conventional refrigeration (Table 4). 'MM106' produced the heaviest and largest fruit, the fruit from this rootstock were also late maturing. 'M26', 'O3' and 'MM102' all produced small early maturing fruit (Table 4). Fruit firmness, varied 0.44 Kg between the softest fruit ('O3') and firmest fruit ('MM106'); interestingly, the early maturing rootstocks were not as firm as the later maturing rootstocks after storage. The levels of greasiness were very low this year, however, the fruit from 'O3' were significantly greasier than all the other rootstocks. Overall, there were no storage type by rootstock interactions, additionally, 'MM106', 'M7' 'M9' and 'MM102' produced large firm fruit, 'O3' produced small soft, greasy fruit and 'M26' produced small fruit (Table 4).

Table 4: The effect of rootstock on fruit quality parameters after storage 2003

		Weight g	TSS %	Firmness kg	Diameter mm	Greasiness % Fruit	Internal browning Severe	% deep red 110-0
CA stored (Av)		129.2	13.1	6.7 b	66.7	0.1	0.0	58.8
Air stored (Av)		123.6	13.1	5.8 a	65.4	4.3	0.0	
Rootstocks (Av)								
M26	19/4/03	119.5 a	13.0	6.17 ab	64.4 a	1.60 a	0.0	48.3
M7	22/4/03	127.3 bc	13.3	6.37 bc	66.5 bc	0.46 a	0.0	58.4
M9	16/4/03	128.9 bc	13.1	6.15 ab	66.4 bc	1.44 a	0.0	55.3
MM102	19/4/03	126.8 abc	12.6	6.30 abc	66.5 bc	1.14 a	0.0	62.8
MM106	22/4/03	133.6 c	12.9	6.51 c	67.3 c	1.72 a	0.0	66.3
O3	16/4/03	122.2 ab	13.6	6.07 a	65.3 ab	6.87 b	0.0	61.8
						Transformed data (x+.5)^.5		
CA vs RA[1]	1,3	10.03	0	325.7	14.22	3.34		
Rootstock	5,30	4.45	2.06	3.73	3.23	2.17	5,15	0.85
Interaction	5,30	0.71	0.19	1.28	0.63	1.04		

[1.] CA = controlled atmosphere and RA = regular air.

Root disease

In both 2001 and 2002, it was found that trees that either showed symptoms of root disease infection, or developed symptoms later, had fruit with extremely high levels of internal browning when compared with trees that showed no symptoms of root disease (Figs 3 &4). This finding strongly suggests that, despite the lack of visual symptoms on the above ground portions of the trees at the time of harvest, the disease was present on these trees and had a major impact on the incidence of internal browning.

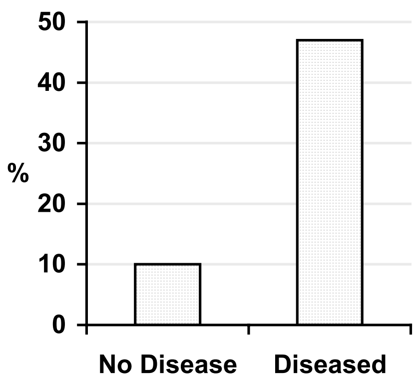


Figure 3. The effect of root disease on internal browning in 2001.

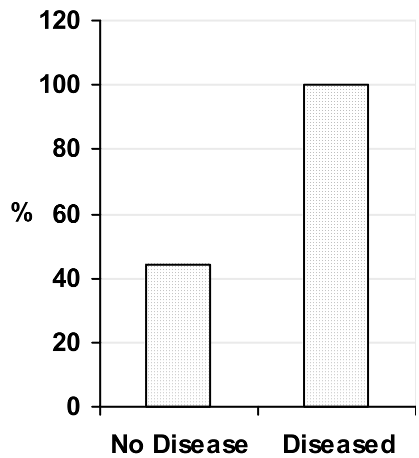


Figure 4. The effect of root disease on internal browning in 2002.

Maturity

In 2001, fruit weight, firmness and TSS remained relatively consistent across the three harvest dates (Table 5) although the starch pattern changed rapidly. At the first harvest, the starch was 93% black, indicating commercial immaturity while by the last harvest, the fruit were considered over-mature, according to the starch pattern.

Table 5: Fruit quality parameters at harvest, 2001*

Harvest	Fruit weight g	Firmness kg	TSS %	Starch %
1	120	10.40	16.7	93.3
2	130	9.68	17.4	75.0
3	126	9.88	16.1	60.7

* Fruit quality parameters averaged across the four rootstocks

Table 6: Fruit quality parameters at harvest, 2002

Harvest	Weight g	Firmness Kg	Diameter mm	TSS %	Starch %
1	170.7	11.4	74	11.8	60
2	173.3	11.6	71	10.1	55
3	189.3	11.1	77	12.4	35
4	191.35	10.4	78	11.5	15

In both 2001 and 2002, the harvest date was important, with the later harvests having a significantly greater incidence of internal browning (Fig. 5). As stated above, based on starch pattern, fruit from the first harvest in 2001 were considered immature (Table 5), however, even this harvest date had some internal browning, suggesting an earlier harvest may be required. In 2002 the starch levels were much lower than in 2001 at the same period (Tables 5 and 6). At 2 weeks before commercial harvest there was only 60% starch, the same level as 1 week after harvest in 2001 (Tables 5 and 6). There were four harvest dates in 2002, and although the first harvest date occurred a week before the first harvest in 2001, the incidence of internal browning at this date was still similar to the first harvest date of 2001 (Fig.5). In both years, the incidence of internal browning increased with later harvests at lower starch levels (Tables 5 and 6, Fig.5). These results suggest that Tasmanian grown 'Pink Lady' apples should be harvested at the first sign of starch movement. However, this does not give sufficient warning to growers in regard to the timing of the picking date; therefore, other methods of predicting harvest date, such as the maturity index, should be explored.

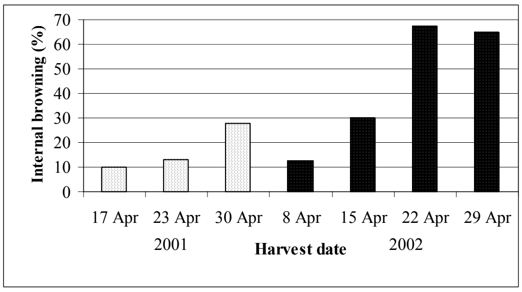


Figure 5. The effect of harvest date on internal browning of 'Pink Lady' apples in 2001 & 2002

Although, fruit quality decreased after CA storage in 2001, there was no significant difference between harvest dates across any of the quality parameters (Table 7). Firmness decreased by an average of 3 Kg, and TSS increase by approximately 1.5%, all fruit were very greasy and had approximately 10% weight loss. In 2002, firmness decreased by an average of 1.8 Kg and TSS increased by 0.7% over the storage period. It appears that the fruit maintain firmness during storage in 2002.

Table 7: Fruit quality parameters of fruit from various harvest dates[@] after storage in 2001

Harvest	Weight loss %	Greasiness %	Internal CO_2 %	Internal O_2 %	Firmness kg	Diameter mm	TSS %
1	11.6	86.0	2.05	18.2	6.79	63.9	18.2
2	8.7	85.3	1.96	18.4	6.91	66.1	18.7
3	6.6	88.4	2.08	18.4	6.67	66.8	18.4
significance[+]		ns	ns	ns	ns	ns	ns
LSD [#]							

[@] fruit quality parameters averaged across the four rootstocks
[+] * = significant to $p<0.05$, n.s.= not significant
[#] LSD = least squared difference

Table 8: Fruit quality parameters of fruit from various harvest dates[@] after storage in 2002

Harvest	Firmness	TSS	Internal browning
	Kg	%	%
1	10.0	11.9	12.5
2	8.8	11.4	30.0
3	8.8	12.0	67.5
4	9.8	12.3	65.0

Maturity index

Although there was some variation, the maturity index (MI) appears to change in a linear fashion, from about 6 weeks before harvest (Fig. 6). This makes the maturity index a useful predictive tool for growers, to determine the optimum maturity for the harvest of Tasmanian 'Pink Lady' apples. From preliminary studies, it appears that a maturity index of 400 indicates the optimum time for harvest, at this date there is potentially enough colour in the fruit, but it does not appear to be very susceptible to internal browning. Therefore growers can determine firmness, TSS and starch and use these to calculate the MI in the weeks before harvest. As indicated in the maturity section, Tasmania 'Pink Lady' apples need to be harvested at the first indication of starch movement. This nullifies any predicative capacity of the starch plates, which is currently the commercial practice to plan harvest for most varieties. The MI may provide a better tool for harvest management in the future.

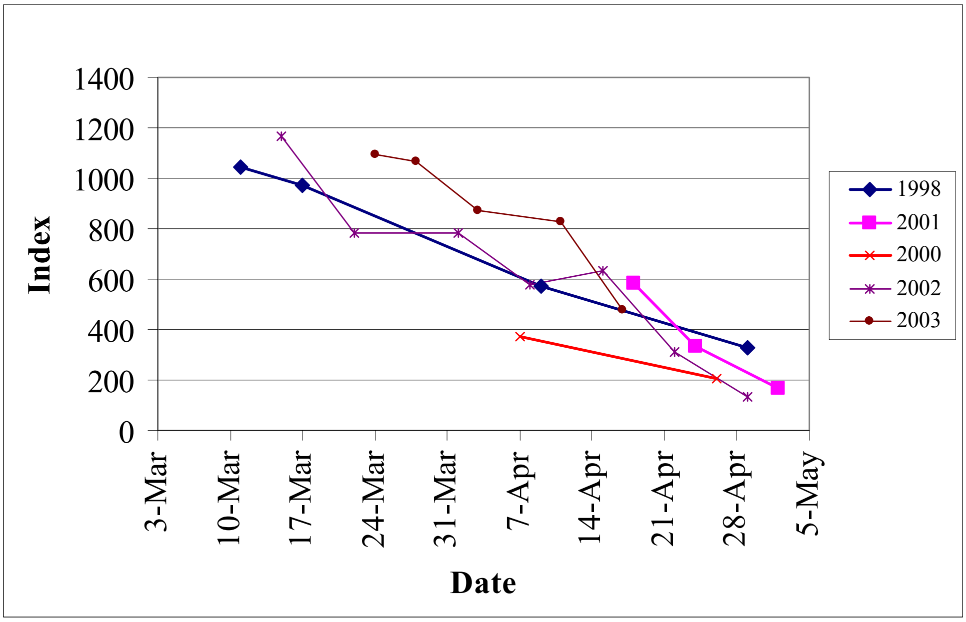
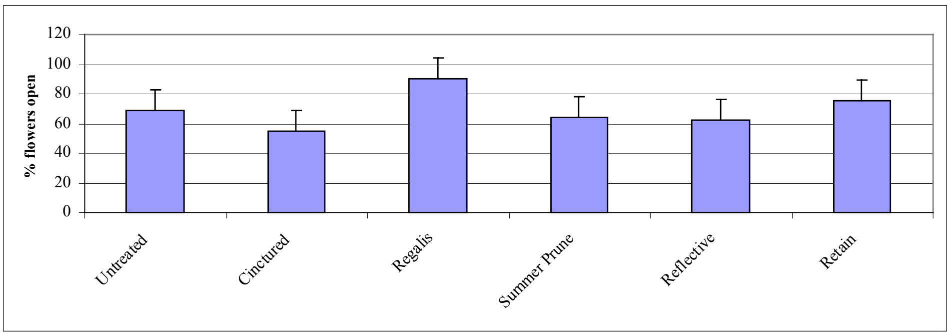


Figure 6. The maturity index of Tasmanian 'Pink Lady' apples in the weeks before harvest.

Growth regulation

Flowering

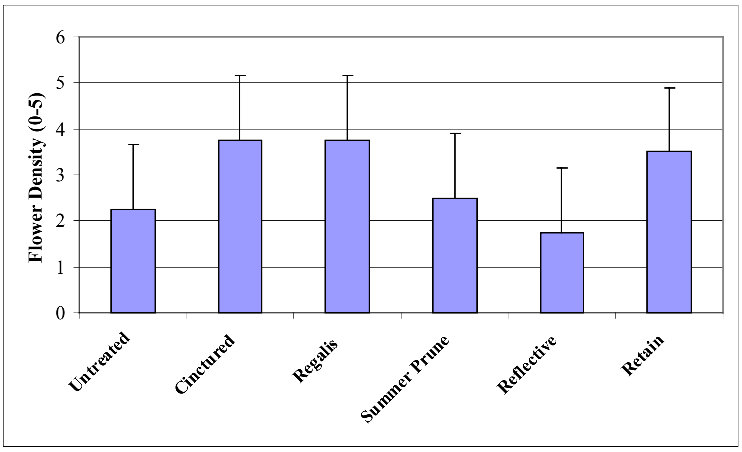
It was found that the application of Regalis® significantly advanced flowering over all other treatments, in the spring of 2002, after the first year of treatment application (Fig. 7). No other treatment was observed to have any effect on flowering date compared to leaving growth unchecked although when compared with one of the industry standard practices, cincturing the trees, it was found that Retain® also advanced flowering date.



Bars represent 5% LSD value

Figure 7. The effect of growth control in 2001/02 on flowering in 2002/03.

Flower density figures (Fig. 8) give an indication on the quantity of flowers on the trees. Here it was found that cincturing the tree or applying Regalis® increased the number of flowers over doing nothing to control tree vigour. While summer pruning and reflective cloth had little impact on the number of flowers on the trees the Retain® treatment resulted in more flowers than the reflective cloth treatment. Hence, Regalis® was observed to advance flowering and increase the total number of flowers. Although not recorded in the trial it was felt that Regalis® compacted the flowering period and hence may help in harvest management.



Bars represent 5% LSD value

Figure 8. The effect of growth control in 2001/02 on flowering density in 2002/03.

Shoot Growth

Shoot growth was recorded on three occasions in both seasons although in the first season this occurred in the first half of the growing season only (Figs 9 and 10). In both cases, by late December, the cinctured trees had shorter shoots to the untreated controls although this difference was more marked in the 2002 season. In both seasons the Regalis® treatment had resulted in dramatically reduced shoot lengths and in the 2002 season were similar to trees that had bee chain sawed through their trunks. It is also worthy to note that the Regalis® treatment had longer shoots to all other treatments in 2002 at the first assessment prior to the material application, further demonstrating the advancement that this material had on bud break and flowering. During the 2002 season good rains in the second half of the growing season caused the shoots in the Regalis® treatment to break free of the material resulting in late season growth, also observed in the untreated treatment but not observed in the other growth controlling treatments. This resulted in average shoot lengths for Regalis® close to the cinctured treatment at harvest. This was not observed in the drier 2001 season.

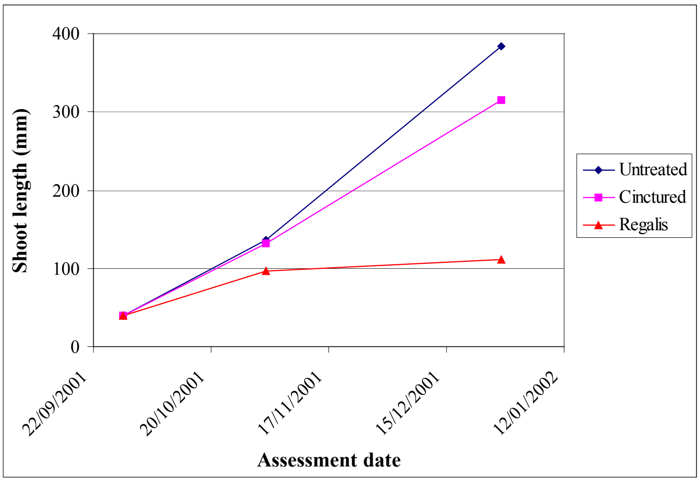


Figure 9. Shoot length of cinctured and Regalis treated trees, 2002 season

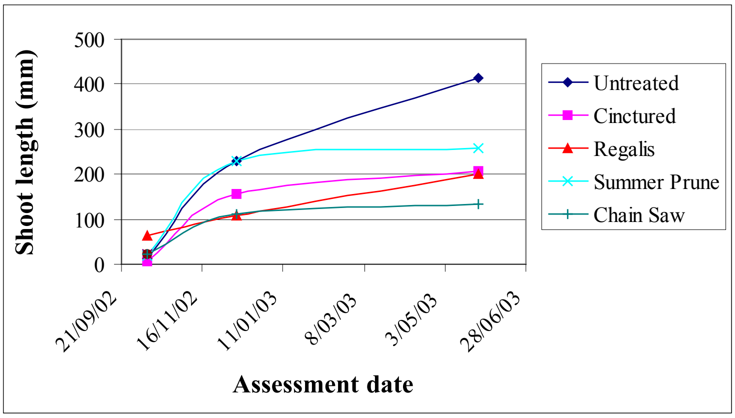


Figure 10. Shoot length of treated trees, 2003 season

Harvest maturity

Physiological harvest maturity is usually measured as the level of sugars, starch and the fruit firmness. The maturity index is a mathematical combination of these three parameters and on the basis of this the treatments had no effect on fruit maturity in the 2002 season (Table 9). It was found, however, that summer pruning resulted in fruit that were softer than fruit from cinctured trees and that fruit from the Regalis® treatment had higher fruit sugars to the reflective cloth and Retain® treatments. There were no treatment effects on fruit size and the cincturing, Regalis®, summer pruning and reflective cloth did improve the important marketing feature of fruit colour while Retain® did not. Of these treatments the reflective cloth proved to be superior to the other treatments (Fig. 11).

Table 9. Harvest maturity and red colour development 2002 season

	Weight (g)	Red colour (%)	Firmness (N)	Sugar (%TSS)	Starch (% black)	Maturity Index
Untreated	169.2 a	27.7 a	111.8abc	12.0 ab	19.2 a	181 a
Cincturing	175.0 a	44.6 b	114.7 c	12.0 ab	17.8 a	173 a
Regalis	172.5 a	44.2 b	109.0 ab	12.5 b	20.8 a	185 a
Summer Pruned	169.3 a	48.0 b	106.8 a	12.0 ab	23.3 a	207 a
Reflective cloth	171.8 a	67.9 c	109.0 ab	11.9 a	20.8 a	193 a
Retain	163.3 a	39.5 ab	113.5 bc	11.7 a	19.2 a	187 a
Significance	ns	**	*	ns	ns	ns
5% LSD	15.4	13.4	5.3	0.64	10	152.0

* significant at $p = 0.05$, ** significant at $p = 0.01$

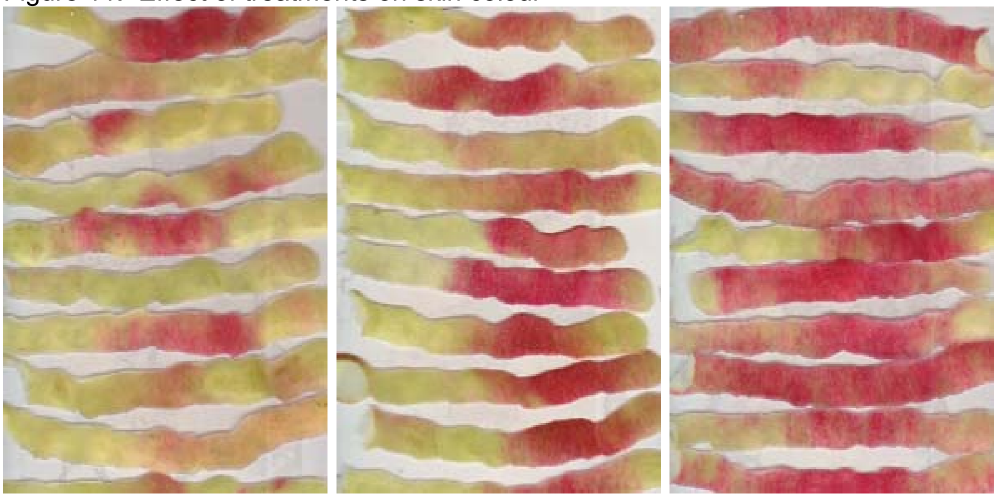
During the 2003 harvest season, samples of fruit for the determination of fruit harvest maturity from individual plots were not taken, such that statistical analysis of treatment effects on harvest maturity were not possible. It was observed, however, from samples taken across the replicates, that while the Ethrel® treatment was expected to advance fruit maturity and hence was harvested one week earlier, based on the previous seasons results, the other treatments were expected to have minimal impact on fruit maturity at harvest. This was not the case however and it was found that the cincturing and chain saw treatment dramatically advanced fruit maturity and the Regalis® treatment, possibly through the advancement of bud break and flowering, were mildly advanced (Table 10).

Table 10. Harvest maturity and red colour development 2003 season

	Weight (g)	Red colour (%)	Firmness (N)	Sugar (%TSS)	Starch (% black)	Maturity Index
Untreated	133	34.2	96.8	12.8	50	378
Cincturing	142	20.3	98.3	12.4	10	79
Regalis	122	36.4	95.8	11.6	20	165
Summer Pruned	141	26.1	97.0	11.1	45	393
Reflective cloth	149	55.9	100.3	12.0	70	585
Ethrel	127	41.5	100.8	11.2	65	585
Chain Sawed	120	39.7	99.5	11.9	5	42

Data from composite fruit sample across replicates and not statistically analysed.

Figure 11. Effect of treatments on skin colour



Cinctured Regalis Reflective Cloth

Stored fruit quality

After long term controlled atmosphere storage, for fruit from the 2002 harvest, it was found that while the treatments had no effect on fruit firmness or sugar content there was a large effect on internal browning of the fruit (Table 11). In this season, all treatments increased internal browning over the untreated controls. Although there was no differences detected between Regalis®, Retain®, summer pruning or reflective cloth it was found that the common practice of cincturing trees resulted in a large increase in internal browning in these fruit (Table 11, Fig.12). Given that the reflective cloth resulted in fruit with fruit much redder (68%) (Table 9) than the market requirements (40%), there is potential to harvest this fruit 1-2 weeks earlier, thereby reducing the possibility of internal browning due to the maturity effects discussed earlier. In 2003, as for 2002 there were no treatment effects on firmness and TSS (Table 11). Internal browning was not encountered during the 2003 season (Table 11, Fig. 12).

Table 11. Stored fruit quality 2002 and 2003 season

Treatment	Firmness (Kg)		TSS (% sucrose)		Internal browning (% apples)	
	2002	2003	2002	2003	2002	2003
Untreated	9.5	8.6	12.1	13.0	21.9 a	0.00
Cinctured	9.6	8.3	11.8	12.7	78.8 c	0.35
Regalis	9.5	9.0	11.6	12.6	48.1 b	0.00
Summer Pruned	9.2	8.9	11.9	12.6	45.6 b	0.00
Reflective cloth	9.2	8.6	12.0	12.8	40.0 b	0.00
Retain/Ethrel	9.6	8.4	11.9	12.5	42.5 b	0.30
Chainsawed		8.2		12.9		0
Sig	ns	ns	ns	ns	*	ns
5% LSD					17.6	

* Significant at p = 0.05. Means in a column the same letter not different, LSD p = 0.05.

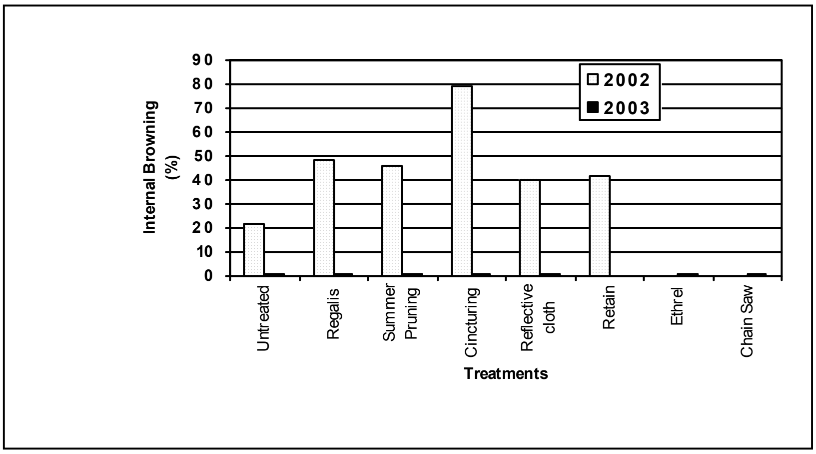


Figure 12. The effect of growth regulators on the internal browning of 'Pink Lady' apples, 2002 & 2003

Conclusion

Fruit maturity, rootstock cultivar and tree health have a large impact on the appearance of internal browning. As the lowest levels of internal browning observed in this trial (harvest 1) were still around ten percent, even fruit from this harvest date were over mature and an earlier harvest may be necessary in Tasmania. At the first harvest the fruit had 16.6% sugars, 10.3 kg firmness and a starch pattern which was 92% black. As starch is the most commonly accepted method of determining harvest date for 'Pink Lady' this suggests that commercial harvest should occur at the first sign of starch breakdown. However, since no warning to growers as to when to start picking, other methods of determining picking date should be explored.

It should also be noted that the tree root health had a large impact on the incidence of internal browning. Fruit from trees which later showed signs of root disease had extremely elevated levels of internal browning.

Internal browning was positively associated with less vigorous rootstocks, therefore, when planting new orchards, vigorous rootstocks that are not susceptible to root disease should be used. If dwarfing rootstocks are planted then no other form of growth control should be used. If internal browning occurs in the orchard, the fruit should be marketed without long term storage.

Controlling tree vigour and picking fruit at a more mature stage are often done to improve fruit colour. Since both of these practices increase the susceptibility to internal browning, methods of growth control which don't increase the incidence of the disorder need to be used. The growth regulation trial has clearly demonstrated that there is an impact of different methods of growth control and improving fruit colour on both tree vegetative vigour and fruit quality. Some of the treatments (cincturing and Regalis®), also have the potential to impact on the economics of the orchard through reduced labour costs associated with tree training. With the exception of Regalis® and Ethrel, all treatments are currently practiced by Tasmanian growers without knowledge of the impact of the treatment on stored fruit quality.

It was found that the level of fruit colour in the untreated control fruit in both seasons was well below the market standard of 40% and hence this is not a viable option to the growers and some method of improving fruit colour is required. While cincturing the trees did reduce the vegetative vigour of the trees and increase the level of fruit colour it also substantially increased the level of internal browning to unacceptable levels. As such, industry should be discouraged from applying this treatment to Pink Lady apples. The Regalis®, summer pruning and Retain® treatments all increased fruit colour in the 2002 season to a similar and acceptable level and the level of internal browning stimulated by these treatments was also similar. Of these treatments Regalis® also eliminated the need for summer and winter pruning providing a large cost saving to the grower. In addition this treatment increased flowering in the following season and may have led to more compacted flowering which may lead to more efficient harvesting procedures. The final treatment, reflective cloth, led to a massive increase in fruit red colour with a similar level of internal browning to the other treatments. Hence this treatment, if adopted, would allow for earlier harvest of fruit with the resultant benefit of reduced internal browning. While summer pruning was not practiced in this orchard the vegetative growth of this treatment will need to be controlled, possibly with winter pruning.

In the 2003 season, that the two treatments that disrupt the water supply to the foliage, cincturing and chain sawing, caused the fruit to mature earlier than the other treatments. The earliness of the Regalis® treatment was probably due to its effect on flowering where it caused earlier bud break and flowering. Overall, in the second season, fruit colouration was not as high at harvest and internal browning of long term stored fruit was not encountered. The treatments with the greatest impact in the second season were Ethrel® (not applied in 2002) and reflective cloths, with the reflective cloths providing superior colouration to all other treatments for a second season.

Recommendations

- Given the necessity to improve fruit colour, reduce the incidence of internal browning and to reduce overall operating costs of orchards it is necessary for more than one technique to be used by orchardists.
- For general tree health, consideration should be given to the use of vigourous rootstocks and soils should be well drained to reduce root disease. If replanting, then consideration should be given to methods of controlling root diseases, especially if they were observed in the previous crop.
- The fruit must be harvested at earlier stages of maturity, in order to maintain the required colour specifications, especially in more vigorous rootstocks, it is necessary to apply treatments for growth control/improvement of fruit colour.
- The effects of cincturing on growth control is minimal and the impact on internal browning too high. It is anticipated that similar results will be obtained for the chain saw treatment. As a result it is recommended that Regalis®, when it becomes available, be used by growers to control vegetative vigour. This treatment in itself will allow for improved fruit colour in healthy orchards with sufficient levels of irrigation and nutrition. If further fruit colouration is required then reflective cloths should be considered, or, depending on the outcomes of the 2004 season Ethrel® may be commercial alternative, although, at this stage it's effect on internal browning is not known and it will need to be registered for this purpose.

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Acknowledgments

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11.3 DPI, Knoxfield Flesh browning

INTRODUCTION

In the Pink Lady firmness project (HAL AP 01036), we have conducted a considerable amount of valuable extra work. This was because flesh browning (FB) appeared in stored apples in 2001 and we recognised its importance. We measured flesh browning and factors that may affect it in 12 orchards in the Goulburn Valley in three harvests, 2001-2003. This work was over and above the work in the Pink Lady firmness project and was funded by DPI Victoria. Some of the results of this work are presented as follows.

11.3.1 EXPERIMENTAL OBJECTIVES

To record the incidence and severity of flesh browning as an extra parameter to firmness for each trial. In this report we present the results from the 2002 UK export trial and weather data collected for the 2001, 2002 and 2003 seasons for the full bloom to harvest period.

11.3.2 MATERIALS AND METHODS

The materials and methods for the export trial are presented in Section 5.4.2.

In 2001, flesh browning was first observed. It had diffuse browning from the outer cortex and almost clear around the core. It was called senescent browning (Plate 1a). In 2002, the symptoms were different and the browning had a radial appearance (Plate 1b). In order to quantify the severity of radial browning observed in 2002 as part of the UK export trial a visual severity rating scale was prepared (Plate 2).

A B C

Plate 1. Flesh browning observed in Pink Lady apples FB type 1 senescent (A), FB type 2 radial(B) and FB type 3 carbon dioxide injury (C).

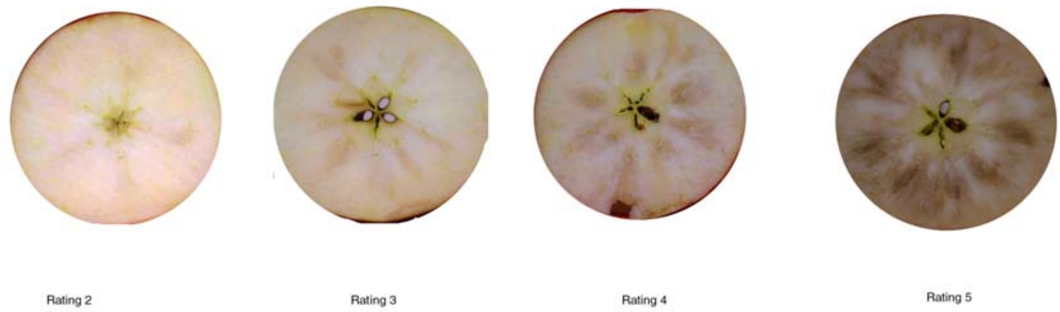

Plate 2 Severity rating scale for radial flesh browning (FB-type2) observed in Pink Lady apples in the 2002 export trial.

11.3.3 RESULTS

UK export trial
The incidence and severity of radial type flesh browning (FB) was measured on fruit sent to the UK in 2002 as part of the SmartFresh^{TM} Pink Lady export trial.

The incidence of FB varied considerably between the 12 orchards (Figure 1). The highest incidence of flesh browning (FB) was recorded for orchard 5 with 70%. Orchards 3, 7and 12 had moderate levels of FB between 20% to 40% and orchards 1,2,8 9 and 11 had 10% to 20% and orchards 4, 6 and 10 had less than 5%.

SmartFresh^{TM} had no significant effect on the incidence of FB, except for orchard 7 where SmartFresh^{TM} significantly reduced the incidence of FB.

A severity rating is an average score, therefore scores approximately 3 would indicate that there is likely to be a high percentage of the fruit with severe FB (Figure 2). The severity varied between orchards with orchards 3,5 and 7 having the highest scores and orchards 6 and 10 having the lowest scores.

The starch index was similar for most orchards, except for orchards 6, 11 and 12 which higher starch levels (see Section 6.2.4 Table 3). Maturity as measured by the starch index does not appear to have affected the incidence of FB.

The risk of orchards getting FB would appear to be orchard specific with some being badly affected with FB and others with very little on no FB.

Possible influence of weather on flesh browning

In the 2001 season there were isolated orchards with approximately 10% incidence of senescent flesh browning (DPI, Knoxfield unpublished data). In 2002, some orchards had up to 70% of fruit with severe radial flesh browning. In 2003, flesh browning was not observed in fruit from orchards associated with this project. As a preliminary look at the weather differences for each season, the temperature data collected from the Tatura Met station was plotted for the period between full bloom and harvest to identify if major differences could be attributed to weather. A polynomial curve was fitted to the data. In addition, rainfall during the same period was quantified.

The polynomial curves for the 2001 and 2003 seasons were relatively similar during years when there was a low incidence and no flesh browning respectively (Figure 3a, b, c and d). The curve for 2002 season was flatter relative to the other two seasons. High incidence of FB occurred in a season with lower spring and summer temperatures and higher temperatures 30 days before harvest. Any possible association of temperature and FB would need to be tested over several seasons. A more sophisticated approach to developing an early warning system would be to calculate the accumulated degree days through out the season and try to quantify it to the incidence and severity of flesh browning,

Rainfall data from the three seasons was also examined. There are clear differences between seasons in respect to the timing and quantity of rainfall (Table 1). In the 2001/2002 season during the full bloom period it was wetter than the other two seasons. During the cell division phase of fruitlet development the 2001/2002 season had half the rainfall of 2000/2001 but five times more than 2002/2003. The 2001/2002 season was also much drier during the month proceeding harvest and during harvest compared to the other two seasons. There is a suggestion that rainfall and irrigation practices should also be further investigated.

11.3.4 TABLES

Table 1. Rainfall data collected at the Tatura Met station the 2000 / 2001, 2001/2002 and 2002/2003 during the full bloom period, 50 days after full bloom, 30 days before harvest and during the harvest period.

Time	Rainfall (mm)		
	2000/2001 season	2001/2002 season	2002/2003 season
Full bloom[1]	3.2	16.4	3.2
50 dafb[2]	207.2	111.8	24.0
30 dbh[3]	29.4	16.6	50.4
Harvest[4]	14.0	2.2	14.6

[1] Full bloom period in 2001 was 1/10/2000 to 11/10/2000
2002 was 27/9/2001 to 5/10/2001
2003 was 2/10/2002 to 9/10/2002

[2] 50 dafb = 50 days before full bloom

[3] 30 dbh = 30 days before harvest

[4] Harvest period was set for 24th April to 5th May for each year

11.3.5 FIGURES

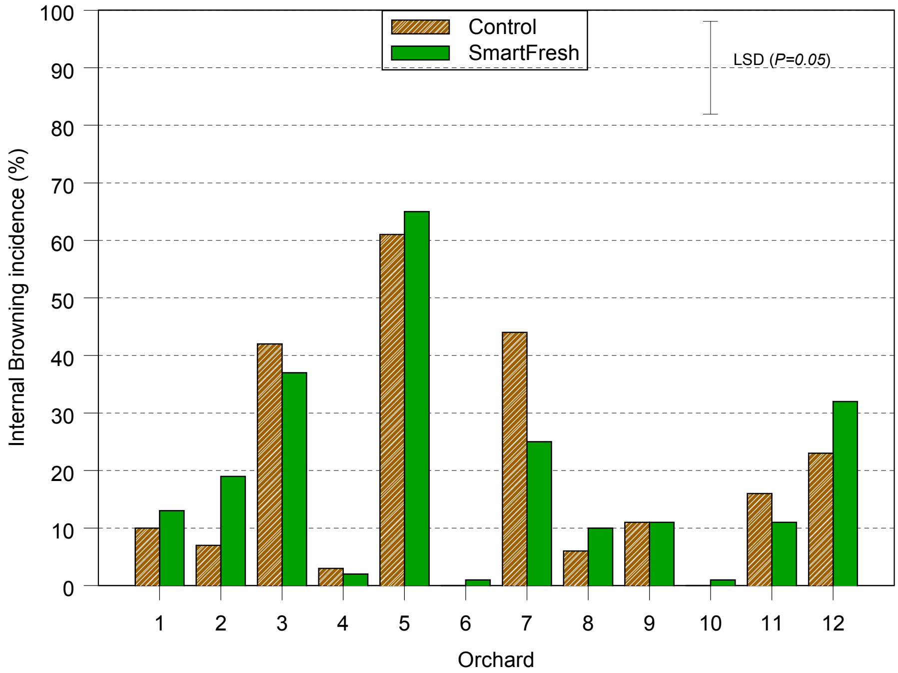

Figure 1. Incidence of flesh browning in Pink Lady apples from 12 orchards in the Goulburn Valley observed in the UK on the 10th October 2002.

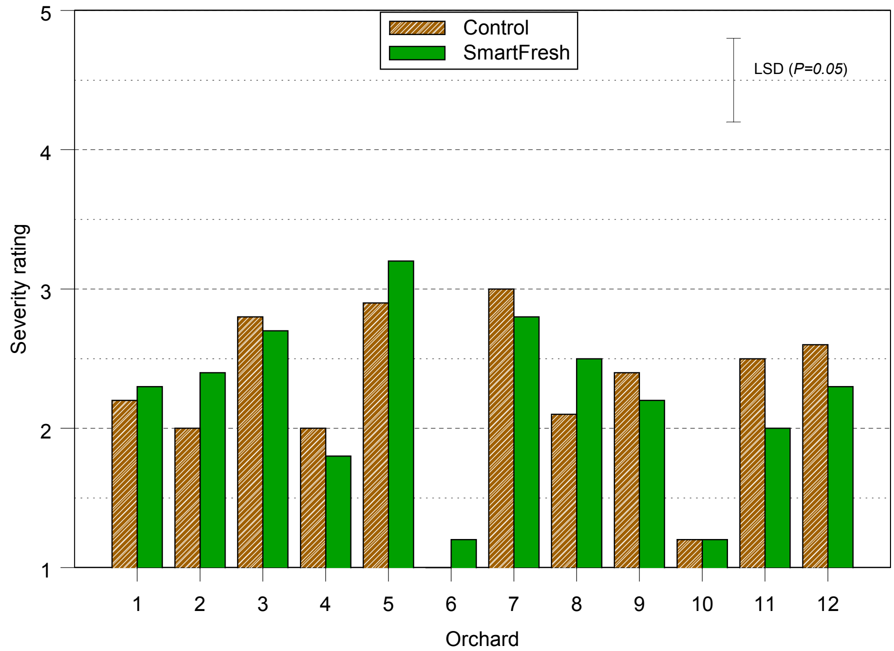

Figure 2. Severity of flesh browning in Pink Lady apples from 12 orchards in the Goulburn Valley observed in the UK on the 10th October 2002.
Severity rating scale: 1 = none, 2 = trace, 3 = slight, 4 = moderate and 5 = severe.

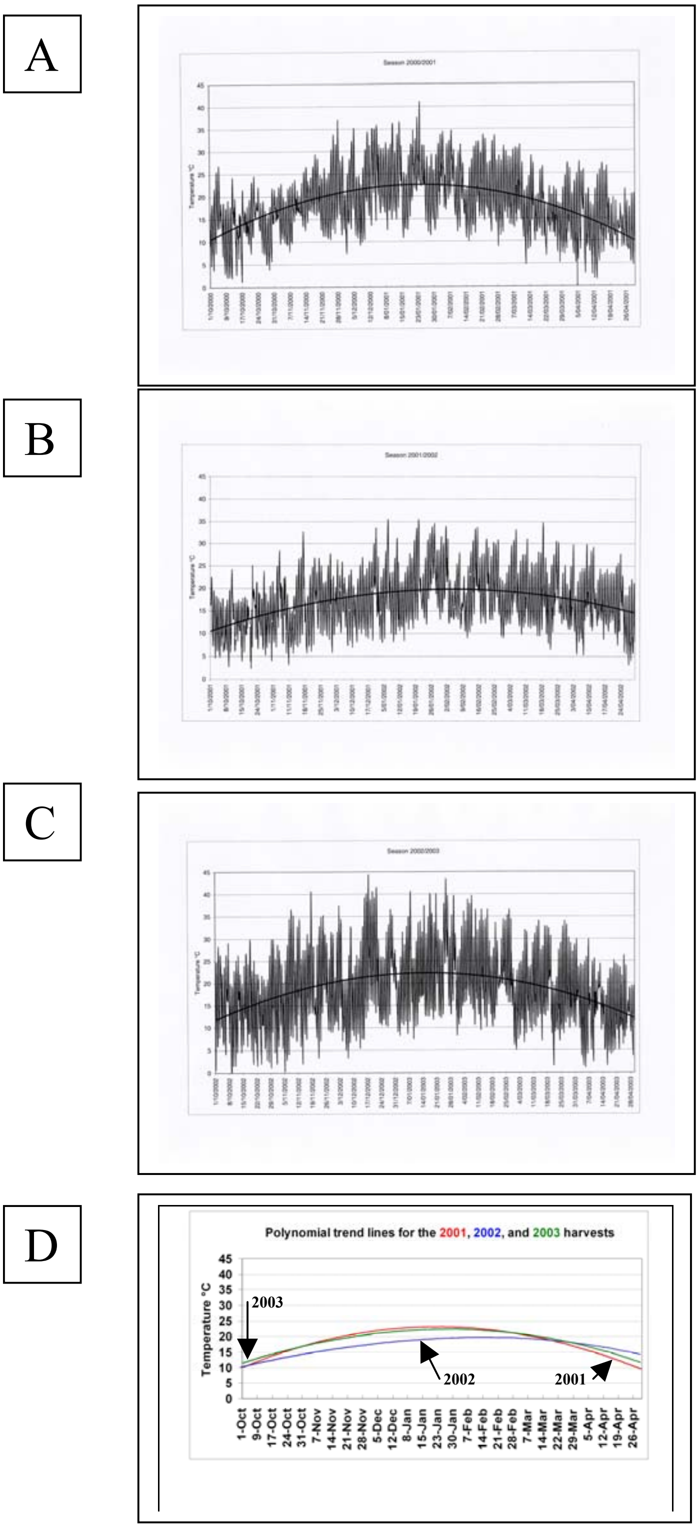

Figure 3. Temperature data collected at the Tatura Met station during the 2001 (A), 2002 (B) and 2003 (C) seasons for he full bloom to harvest period and the polynomial curves for each season (D).

12. CONCLUSIONS

SmartFresh^{TM}

- SmartFresh^{TM} is a new apple firmness management tool for growers.
- SmartFresh^{TM} significantly increased Pink Lady, Jonagold and Gala apple firmness after medium to long term air and CA storage.
- SmartFresh^{TM} significantly increased Pink Lady apple firmness after shipping to the UK by 0.5 to 2.0 kgf. There are variations due to season and orchard. Treated fruit that depart Australia with a firmness of 7.5 kgf or greater with less than 10% of the fruit at less than 7 kgf should arrive in the UK within or better than the minimum market specifications.
- In the 2001 trials, treating fruit with SmartFresh^{TM} at 1000 ppb was equally effective as 10,000 ppb in maintaining fruit quality. In 2002 and 2003 trials excellent firmness results were achieved using SmartFresh^{TM} at 625 ppb.
- SmartFresh^{TM} should not be used as a substitute for refrigeration but it can be used to insure against firmness loss under sub-optimum storage conditions that can occur during shipping or in retail displays.
- SmartFresh^{TM} is effective when applied to warm or cooled fruit. Growers can treat the fruit immediately after harvest while the fruit is warm or the fruit can be cooled and treated within a fortnight of harvest.
- SmartFresh^{TM} treated fruit stored in air can be as firm as CA stored fruit after long term storage.
- There were no significant additional benefit of SmartFresh^{TM} on fruit firmness by treating the fruit a second time after storage or immediately prior to sea-freight.
- SmartFresh^{TM} is not a replacement for CA, but it could be used to extend the storage life of air stored fruit.
- A temptation for growers will be to delay the harvest of Pink Lady apples to obtain better colour and size then treat the fruit with SmartFresh^{TM} to preserve firmness. Potentially this may be possible but until we have more information on how late harvested fruit respond, the fruit should be picked as close to optimum maturity as is commercially feasible.
- Overall, SmartFresh^{TM} did not significantly effect the TSS content of the fruit. However, in the simulated sea-freight trials air stored fruit treated with SmartFresh^{TM} before storage and shipped in air had significantly higher TSS content than untreated fruit.
- Fruit ground colour (skin greenness) can benefit from SmartFresh^{TM} but the results are not as clear cut as for fruit firmness. In the simulated sea-freight experiment SmartFresh^{TM} treated fruit were significantly greener after simulated sea-freight in air to the UK and as green as fruit shipped in CA. SmartFresh^{TM} treated fruit stored in CA and shipped in CA or air were significantly greener than air stored fruit shipped in air
- SmartFresh^{TM} had no significant effect on the incidence and severity of flesh browning in Pink Lady apples.
- Flavour was not assessed as apart of this project. Rohm and Haas reports suggest that SmartFresh^{TM} treated fruit have a similar flavour and aroma to CA stored fruit for the same storage period. In addition, there is some evidence that consumers prefer the taste of SmartFresh^{TM} treated fruit compared to untreated CA stored fruit. However, the Australian apple industry will need to evaluate the Australian consumer preference

for SmartFresh™ treated fruit stored in air or CA over short and long term storage periods to determine its value as an apple quality management tool.

Maturity and storage

Overall, fruit from the first harvest was significantly firmer than fruit from the second harvest after long-term storage. Firmness was not strongly linked to starch levels, however, earlier picked fruit were firmer and remained that way after harvest compared to later picked fruit.

Generally, if the fruit goes in firm it will outturn firm. This was true for the 2001 and 2002 harvests but in a bad drought year (2003 harvest) fruit lost firmness more rapidly in storage. For orchard 5 data, in 2001 and 2002 the fruit firmness at harvest was greater than 8 kgf at the 2^{nd} pick and the outturn firmness after 6 months CA storage was good at 7.1 kgf. In the 2003 harvest the firmness had 'bolted'. The starch scores were comparable with the other orchards but the fruit firmness at harvest was low (6.9 kgf) at the 2^{nd} pick. The nutrient status of the fruit was adequate for long term storage. It would appear that this fruit was stressed in the orchard, possibly due to drought. The export trial demonstrated firmness loss was arrested by SmartFresh™.

The firmness of the fruit should be monitored proceding and during the harvest period. In a non drought season if the fruit is harvested with a firmness greater than 8 kgf with less than 10% of a sample population less than 8 kgf then with good post harvest management it should outturn well after long term storage and would be suitable for export.

Firmness at harvest can be more of a limiting factor if the fruit is destined for the export market. In this project fruit from the second harvest closely matched the dates when the growers started harvesting the same orchard. Over the three years this trial was conducted the fruit from all of the collaborating orchards picked on the commercial harvest date met the industry standard of 6.5 kgf after long term storage. The firmness standards for the export market demand that the fruit firmness is greater than 7 kgf with no more than 10% of the fruit 6.0 kgf to 6.9 7kgf. Therefore, to meet an export market the fruit firmness at harvest needs to be at least 8 kgf.

Most growers in the Goulburn Valley pick from Pink Lady trees three times. The first pick is a colour pick and fruit is sold for cash flow. Unfortunately, this is the best fruit that should be going into long term storage. The second pick is for long term storage and the third is usually for immediate sale but if there is glut, it goes into storage until the market improves. The domestic market colour standards were lowered in 2003 to 40% to 50% blush, comparable with export standards. Therefore, the minimum starting point for harvest is going to be based on colour. Starch tests are good if they match the minimum colour standard, but there is a tendency for some growers to leave the fruit on the tree longer to get more than the minimum colour. As a result the starch levels drop below the level optimum for long term storage. A major economic consideration for growers is the potential for fruit to size up substantially in the harvest window period between optimum physiological maturity, based on starch and the commercial harvest time, ten days later. Gains of 1.6 tonnes per hectare in this period are possible. But the grower is banking on CA technology to arrest the firmness loss. For most CA operations today this may be possible for firmness, but it may prove disastrous for fruit in a bad flesh-browning year.

Ethylene is a major limiting factor to firm fruit outturns. This was demonstrated by the use of SmartFresh^{TM} to block ethylene action which significantly increased fruit firmness for all orchards. Therefore, if possible, the rooms need to be scrubbed for ethylene while the rooms are being filled and during storage. In addition, the fruit needs to be cooled rapidly after harvest and stored promptly in 1.5% oxygen. The alternative to ethylene scrubbing is treating the fruit with SmartFresh^{TM}.

In the experimental air storage trials the results suggest that when the fruit was stored under excellent temperature management with rapid cooling, as was provided at DPI, Knoxfield, fruit from some orchards outturned firmer compared to commercially stored fruit. Therefore, rapid cooling and maintenance of excellent storage temperature can improve fruit firmness.

Shipping temperature

Maintaining the cool chain is a basic postharvest principle for maintaining fruit quality. Apples should be held at close to 0^{o}C to minimise quality loss. In the simulated shipping trials and the SmartFresh^{TM} trials, the effects of 6 weeks simulated shipping at 4^{o}C on fruit firmness was variable. In some trials there was a significant reduction in fruit firmness at 4^{o}C compared to maintaining the coolchain at 0^{o}C. The response of the fruit to poor storage temperature was dependent on the orchard of origin. Given that it likely that shipping containers will have hot spots then it is probable that shipping temperature will limit consistently firm outturns in the UK for fruit from some orchards.

In this project we attempted to compare optimum harvest maturity with commercial harvest maturity. The starch levels for the 2nd pick commercial harvest were approximately 7.5 Ctifl. A starch level of 7.5 Ctifl is only slightly above where traditional starch scores are expected to be for medium term storage. For medium term storage a starch score between 5 and 7 is considered acceptable. Australian Pink Lady apples are wanted in the UK up to the end of October. This means that Pink Lady apples for export need only be stored for medium term CA storage up to early September (allowing for a 4 to 5 week shipping time). Therefore, if the fruit can be harvested with a firmness of 8 kgf or greater and a starch score of approximately 7 and provided skin blush, intensity and total soluble solids and storage conditions are not limiting factors the fruit has a high probability of meeting the export firmness standard.

Nutrition

The industry wanted to know if foliar sprays applied during the early fruitlet stages could correct mineral imbalances in time to achieve normal levels at harvest.

In this project the results were inconclusive. The nutrient levels did improve between the 25 gram and 55 gram fruitlet stages as a result of the higher input applied between the 25 gram and 50 gram fruitlet stages. However, there were also orchards on lower nutrient inputs with fruit of similar nutrient levels 90 DAFB and at harvest.

In two drought years that the higher nutrient input was trialed, there was no evidence that the early warning system wasn't working. The drought conditions were probably having a bigger effect on fruit firmness than the nutrient levels in the fruit. Nutritional studies are usually run over many years and nutritional programs such as Phosyn's full nutritional program can take several years before the full benefits are achieved. Therefore, more years of evaluation are needed to clarify the benefits of early warning nutrient correction system, hopefully not in drought conditions.

Overall there appears to be a need to get more sprays on during the 50 DAFB (cell division phase) to maximise the mineral levels and improve firmness, colour and return bloom. The best results are obtained from foliar sprays if applied when humidity is high, temperatures are less the 25°C, light intensity is low, young foliage is fully turgid. The pH of the mixture should be slightly acid and the leaf area should be thoroughly wetted.

Further work is needed to determine the optimum nutritional levels for Pink Lady apples. This project used standards as provided

DPI, Knoxfield will continue to work with Phosyn in analysing the full set of mineral data and the results will be made available to the industry when they are complete.

Calcium dipping has been shown for other apple varieties to improve fruit firmness outturn. In this project, there was no significant effect of "Stopit" calcium dip (16% calcium as calcium chloride) used at the rate of 1.35 litres per 100 litre of water on fruit firmness after 8 months CA storage. This has also been confirmed by Gordon Brown in the HAL funded project on 'Jonagold' apples (AP99031). The failure to achieve a significant result may have been due to: 1) the recommended rate being too low to benefit fruit firmness, in order to reduce the risk of lenticel injury and 2) the fruit was not dipped on the day it was picked, although research is needed to confirm this hypothesis.

Crop load and tree vigour

The crop load and tree vigour need to be looked at in relation to the nutritional status of the fruit. It may be possible to carry two consecutive high yielding years provided the trees vigour is reduced and the nitrogen to calcium ratio is low allowing high calcium availability for the fruit.

Weather and microclimate

Orchard temperature (accumulated degree-days) was not significantly different between the orchards and was therefore not seen as a major limiting factor for firm fruit. However, the proximity of orchards 1, 4, 9 and 10 to the Goulburn river was thought to produce a microclimate conducive to red colour development and thus earlier harvesting (closer to optimum for long term storage).

Flesh browning

The causes of flesh browning (FB) in Pink Lady apples are not well understood. It is most likely a combination of several factors that stress the fruit before harvest and postharvest conditions.

- There is likely to be more than one type of flesh browning. This project has characterised three types, Type I: senescent, Type II: radial, and Type III: carbon dioxide injury. Each type may be the manifestation of different precursors.

- Seasonal variation has an impact on FB as it was absent in 2003. How the weather interacts with the cultural practices or locations of individual orchards is not known.
- SmartFresh™ does not appear to affect the incidence or severity of flesh browning. This would suggest that the problem is independent of ethylene action.
- Late picked, over mature fruit are more susceptible to FB.
- Diseased root systems, less vigorous root-stocks and cincturing are factors that can increase the risk of fruit developing FB.
- Regalis® and the use of reflective cloth may reduce the risk of FB by reducing tree vigour and advancing colour development which avoids having to pick over mature fruit.
- During this project fruit from several orchards have been stored at 0°C and in a CA storage atmosphere of 2.5% O_2 plus 1% CO_2. Fruit from some orchards developed FB others did not, even though they were stored in the same tent. This suggests that the problem was orchard specific and that the fruit was pre-conditioned to the disorder prior to storage. In addition, the carbon dioxide level should not exceed 1% or FB-type 3 may occur.
- If we knew why two orchards less than half a kilometer apart can differ so greatly in the incidence and severity of FB then we may have the answers to predict or develop strategies for avoiding the problem in the future.

Some of the unknown factors that could be affecting fruit firmness that were not addressed in this project are:

- Water stress.
- Fruit tissue density and cell size.
- Canopy density in relation to summer pruning.
- Seasonal weather conditions temperature, relative humidity, and sunshine hours in the preceding season.
- Tree health management.
- Fruit respiration rates at harvest.
- Storage humidity.

In hindsight this project attempted to monitor too many parameters across many properties. It may have been prudent to work with fewer orchards, maybe even one orchard with a history of soft fruit outturns. In the latter situation we could divide the orchard up into a number of experiments whereby only one factor was changed at a time.

The project was designed to investigate macro-effects not the micro-effects. Further work is recommended to investigate the micro-effects responsible for orchard differences in fruit firmness.

13. TECHNOLOGY TRANSFER

13.1 Publications

- 'Tracking Pink Lady apple firmness" an article for NVFA Technical Bulletin based a talk by Ian Wilkinson 20th March 2002 at SPC/Ardmona PL.

13.2 Meetings and presentations

- On the 24th May 2001 a meeting was convened at the Institute of Sustainable Irrigated Agriculture to report on the results to date and to plan the following season's trial work.

  The original project proposal aim was to have 6 properties on which a block of trees would be on the complete Phosyn nutrient correction program and the other block the grower would use his existing nutrient program. The logistics of achieving this aim using the growers spray unit and the difficulty of ensuring the two blocks of trees were not cross contaminated by the two spray regimes meant that another strategy had to devised. It was decided to make the orchards experimental replicates and expand the number of blocks from 6 to 12. The aim was to have blocks ranging from poor to excellent fruit nutrient status of which some will be on a full Phosyn nutrient correction program and to correlate the fruit nutrient status with fruit firmness.

- ***"Getting the nutrient analysis work back on track"*** A meeting was held at IHD, Knoxfield on the 17th April 2002 to review the nutrient status work. Present were Nick Sanders Phosyn PL and Bruce Tomkins and Ian Wilkinson DPI.

- ***"Getting the nutrient analysis work back on track"*** A meeting was held at the Holiday Inn St Kilda Rd. on the 23rd April 2002 to review and plan the nutrient analysis work. Present were Steve Howse, Mark Ridings, Michael Waites, Nick Sanders from Phosyn PL and Bruce Tomkins and Ian Wilkinson DPI.

- ***"2001 nutrient analysis results presented to growers participating in the full Phosyn nutrient program".*** A meeting was held in Shepparton on the 23rd October 2002. Present were Nick Sanders Phosyn PL, Ian Wilkinson DPI, Colin Little private consultant and growers Mark Morey, Jim Ymer, Alex and Skinda Kaso, Phillip Pullar and Duncan Brown.

- ***"Progress report and planning meeting for nutrient analysis work".*** A meeting was held on the 24th May 2002 at IHD, Knoxfield with John Brookes UK Phosyn to discuss the project progress and plan for the UK visit. Present were Nick Sanders Phosyn, Colin Little private consultant, Bruce Tomkins and Ian Wilkinson DPI.

- ***"Tracking Pink Lady apple firmness and flesh browning project summary"*** was presented to Dr Angelo Zanella Laimburg Italy on the 3rd October 2002.

- ***"A summary of 1-MCP work done at IHD, Knoxfield"*** was presented to Chingford Fruit Packers UK which included the Pink Lady work, on the 8^{th} October 2002.

- ***"A summary of 1-MCP work done at IHD, Knoxfield"*** was presented to Rohm and Haas PL in Philadelphia, USA on the 14^{th} October 2002.

- ***"Tracking Pink Lady apple firmness summary of results so far"*** was presented at the AFFCO AGM, at the Stanford Hotel Glenelg, Adelaide 19^{th} October 2002. A copy of the presentation is attached to this CD as an acrobat .pdf file.

- ***"Pink Lady UK outturn results".*** On the 20^{th} November the results of the Pink Lady UK outturn results were sent to all 12 growers participating in the project.

- ***"IHD, Knoxfield SmartFresh^{TM} (1-MCP) projects overview presented to Jane Turner, the new Australasian manager for SmartFresh^{TM}".*** Meeting held at IHD, Knoxfield on the 27^{th} November 2002. Present were John Faragher and Ian Wilkinson DPI and Nic Tydens Agrisearch.

- Flesh browning observations in the AP 01036 project was presented at the AFFco workshop held at Attwood, DPI on the 12^{th} December 2002.

- "Effect of SmartFresh^{TM} on apples and pears" talk presented at the AFFco World Class Apple Workshop "Moving towards world best practice" 31^{st} May 2003.

- "Update on the Tracking Pink Lady apple firmness project". AFFco Pink Lady technical workshop, 16th October 2003 at Primary Industries Research Victoria-Knoxfield.

- "Update on SmartFresh^{TM} work from the Tracking Pink Lady apple firmness project". AFFco Pink Lady technical workshop, 16th October 2003 at Primary Industries Research Victoria-Knoxfield.

13.3 Implementation

SmartFresh^{TM} became available in April 2004 and some coolstores are trying it for the first time on Pink Lady apples from the 2004 harvest.

14. RECOMMENDATIONS

1. Soft fruit outturns appear to be orchard specific. A history of each orchard would be a valuable problem solving tool. We recommend growers keep management details of individual blocks and link this to postharvest performance records for fruit from that block.
2. Fruit should be picked close to the optimum starch score of 4.5 Ctifl or the DPI 10 point scales for Pink Lady apples, because this, combined with fruit firmness greater than 8 kgf and less than 9.5 kgf minimises the risk of soft outturns after long term storage.
3. The Ctifl 10 point starch chart is currently the best available starch rating chart. However, the DPI 10 point chart should be considered as an alternative given that the plates are actual photographs of iodine stained Pink Lady apples, not stylised radial type staining patterns.
4. It is realistic to pick the fruit for medium term CA storage if it is going to be exported no later than mid-September. However, with this strategy the postharvest cooling and CA establishment, needs to be prompt. Ethylene scrubbing during room filling and storage is advised and storage in 1.5% oxygen and less than 1% carbon dioxide is preferable.
5. SmartFresh™ can be applied immediately after harvest and excellent firmness outturns for Pink Lady apples should result, if picked at the correct maturity.
6. If treatment is not possible the same day the fruit is picked, SmartFresh™ should be applied within 12 days of harvest.
7. The temptation for growers will be to use SmartFresh™ after harvest to enable fruit to be left longer on the tree, to colour. This should be resisted until such time that it has been shown to be safe for this purpose. There is a need to evaluate SmartFresh™ effects on late harvested fruit firmness in relation to storage time and flavour development.
8. Treating fruit with SmartFresh™ after storage, prior to sending it to the UK is not recommended because it does not appear to significantly improve outturn quality.
9. A method needs to be developed for determining the maturity variation within an orchard. A twenty fruit sample is probably not a good representation of the maturity status of the orchard. Part of the problem with soft outturns is due to variability of fruit firmness at harvest. If the orchardist knows that the trees in an orchard are carrying fruit with a highly variable firmness then he will be better placed in his decision making to it determine its ultimate market destination.
10. Trees' vegetative growth needs to be settled down and the canopy opened up to maximise light penetration into the tree to improve fruit colour development.
11. Balanced fruit nutrition is not a short-term investment. The orchardist needs to have fruit and leaf nutrition analyses done at the fruitlet stage each year to determine fertigation and foliar spray needs and to optimise the nutrient levels for improving firmness outturns.
12. It is proposed that the minimum fruit firmness for export should be 7.5 kgf, to minimise the risks of soft fruit outturns in the UK.
13. Growers are recommended to use the fact sheets for minimising firmness loss of Pink Lady apples for domestic and export markets (see Section 17.2 Appendix B).

15. ACKNOWLEDGMENTS

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All of the growers who kindly allowed us to harvest fruit and conduct trials on their properties.

Preparing fruit for the Tracking Pink Lady apple firmness trial experiments, (left to right) Christine Frisina, Norm Morrison, Glenn Hale, Andrew Hamilton and Mark Collins.

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17. APPENDIX

17.1 Appendix A

MINERAL ASSESSMENT ON APPLE FRUIT TAKEN AT OPTIMUM MATURITY FOR LONG TERM 'CA' STORAGE.

NITROGEN. (N). (expressed as a % of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
0.08	0.11	0.14	0.16	0.18	0.20	0.22	0.24	0.28	0.33	0.38
0.10	0.13	0.15	0.17	0.19	0.21	0.23	0.27	0.32	0.37	0.42

* LLL = extremely low. LL = very low. L = low. LH= high side of low. AL = low side of adequate. A = Adequate. AH = high side of adequate. HL = low side of high. H = high. HH = high side of high. HHH = exceptionally high. The range AL to AH. shown in red, is the recommended operational range

PHOSPHOROUS (P). (expressed as a % of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
0.01	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.12	0.15	0.17
0.02							0.11	0.14	0.16	0.18

POTASSIUM (K). (expressed as a % of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
0.20	0.31	0.42	0.53	0.63	0.67	0.71	0.77	0.88	1.09	1.25
0.30	0.41	0.52	0.62	0.66	0.70	0.76	0.87	1.08	1.24	1.40

CALCIUM (Ca). (expressed as a % of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
0.015	0.019	0.023	0.027	0.031	0.035	0.039	0.042	0.044	0.048	0.052
0.018	0.022	0.026	0.029	0.033	0.037	0.041	0.043	0.045	0.051	0.055

MAGNESIUM (Mg). (expressed as a % of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
0.011	0.016	0.020	0.024	0.027	0.030	0.033	0.036	0.039	0.044	0.049
0.015	0.019	0.023	0.026	0.029	0.032	0.035	0.038	0.043	0.048	0.051

SULFUR (S). (expressed as a % of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
<0.01	<0.01	0.01	0.02	0.03	0.04	0.05	0.06	0.07	>0.07	>0.07

MANGANESE (Mn). (expressed as parts per million of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
1	2	3	5	7	10	13	16	18	20	24
1	2	4	6	9	12	15	17	19	23	27

COPPER (Cu). (expressed as parts per million of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
0.5	2	4	6	7	8	9	10	11	12	14
1.0	3	5							13	15

ZINC (Zn). (expressed as parts per million of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
0.2	0.5	1.0	3	5	7	9	12	15	19	23
0.3	1.0	2.0	4	6	8	10	13	17	21	26

BORON (B). (expressed as parts per million of the dry matter content)

LLL	LL	L	LH	AL	A	AH	HL	H	HH	HHH
7	10	13	16	18	20	22	25	28	32	36
9	12	15	17	19	21	24	27	31	35	+++

Table 1. Mineral level assessment chart for Pink Lady apples at harvest, provided by Colin Little.

Table 2. The complete mineral analysis (dry wet and wet analysis) for the 25 gram fruitlets from 12 orchards in the Goulburn Valley in the 2002 season.

Orchard	N % dw[1]	N % fw[2]	P % dw	P % fw	K % dw	K % fw	Ca % dw	Ca % fw	Mg % dw	Mg % fw	S % dw	S % fw	Zn ppm dw	Zn ppm fw	Cu ppm dw	Cu ppm fw	Mn ppm dw	Mn ppm fw	B ppm dw	B ppm fw
1	0.51	74.40	0.14	20.80	1.37	198.3	0.13	18.4	0.09	13.10	0.05	7.20	12.62	0.18	0.90	0.01	9.61	0.14	28.15	0.41
2	0.65	96.10	0.13	20.00	1.28	189.7	0.09	13.3	0.08	11.79	0.06	8.20	18.47	0.27	1.04	0.02	5.34	0.08	16.10	0.24
3	0.56	78.50	0.12	16.50	1.41	196.1	0.13	18.1	0.09	13.01	0.06	7.80	26.40	0.37	2.28	0.03	10.89	0.15	24.45	0.34
4	0.44	76.00	0.13	22.70	1.26	220.3	0.11	18.4	0.09	15.64	0.05	8.90	13.31	0.23	4.16	0.07	9.37	0.16	17.39	0.30
5	0.77	95.80	0.16	19.80	1.44	178.6	0.14	17.9	0.10	11.86	0.07	8.10	13.70	0.17	1.55	0.02	14.51	0.18	30.48	0.38
6	0.75	105.5	0.14	19.60	1.35	189.3	0.09	12.2	0.07	10.36	0.06	8.60	9.92	0.14	0.75	0.01	6.16	0.09	21.42	0.30
7	0.87	113.1	0.15	19.00	1.44	187.8	0.11	14.8	0.10	12.64	0.07	9.60	24.89	0.32	1.65	0.02	8.91	0.12	26.30	0.34
8	0.48	70.50	0.15	21.20	1.33	194.1	0.15	22.3	0.09	13.77	0.05	7.70	12.40	0.18	1.89	0.03	8.08	0.12	25.62	0.37
9	0.37	50.70	0.12	16.60	1.17	161.8	0.12	16.1	0.08	10.38	0.05	6.60	25.21	0.35	1.18	0.02	7.96	0.11	37.17	0.51
10	0.27	39.10	0.12	17.60	1.33	190.7	0.12	17.3	0.07	10.31	0.04	6.00	9.73	0.14	0.65	0.01	8.72	0.13	31.94	0.46
11	0.74	102.1	0.14	19.80	1.56	215.5	0.11	15.2	0.09	12.09	0.06	8.50	12.57	0.17	1.07	0.01	16.65	0.23	24.32	0.34
12	0.70	99.20	0.13	18.20	1.20	171.6	0.09	12.6	0.07	10.38	0.05	7.50	11.58	0.17	1.63	0.02	7.05	0.10	27.77	0.40

N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulphur, Zn = zinc, Mn = manganese and B = boron..
[1] dw = dry weight, [2] fw = fresh weight.

Table 3. The complete mineral analysis (dry wet and wet analysis) for the 55 gram fruitlets from 12 orchards in the Goulburn Valley in the 2002 season.

Orchard	N % dw	N % fw	P % dw	P % fw	K % dw	K % fw	Ca % dw	Ca % fw	Mg % dw	Mg % fw	S % dw	S % fw	Zn ppm dw	Zn ppm fw	Cu ppm dw	Cu ppm fw	Mn ppm dw	Mn ppm fw	B ppm dw	B ppm fw
1	0.26	44	0.08	14.5	0.83	142.6	0.06	10.9	0.05	8.45	0.02	3.8	5.50	0.09	1.93	0.03	7.16	0.12	25.30	0.44
2	0.25	48.7	0.08	14.6	0.84	161.4	0.05	10	0.05	8.67	0.01	2.7	16.00	0.31	2.42	0.05	6.20	0.12	15.30	0.29
3	0.26	48.4	0.06	11.7	0.80	151.3	0.06	10.8	0.05	8.88	0.02	3.8	17.00	0.32	3.24	0.06	7.48	0.14	20.30	0.38
4	0.21	38.2	0.07	12.4	0.69	127.4	0.05	9.2	0.05	9.03	0.03	5.3	5.49	0.1	2.80	0.05	6.20	0.11	14.00	0.26
5	0.24	43.2	0.08	13.8	0.83	148.9	0.06	10.4	0.04	7.86	0.01	2.5	3.79	0.07	2.07	0.04	7.30	0.13	25.00	0.45
6	0.36	60.6	0.08	13.3	0.84	139.9	0.05	7.5	0.04	7.16	0.03	4.2	9.14	0.15	1.60	0.03	8.80	0.15	21.50	0.36
7	0.30	55.3	0.07	13.5	0.90	168.3	0.04	8.2	0.05	8.78	0.03	5.1	12.60	0.24	1.96	0.04	6.67	0.12	24.70	0.46
8	0.21	38.7	0.08	14.7	0.87	160.5	0.07	13.2	0.05	8.63	0.02	4.3	12.70	0.23	2.57	0.05	6.80	0.12	24.60	0.45
9	0.19	31.7	0.08	13.5	0.90	153.3	0.06	10.4	0.05	7.66	0.02	3.4	20.20	0.34	1.15	0.02	6.67	0.11	33.00	0.56
10	0.17	29.8	0.07	12.4	0.88	153.6	0.08	13.2	0.04	7.67	0.02	3.8	5.82	0.1	1.79	0.03	6.87	0.12	25.00	0.44
11	0.32	55	0.08	12.9	0.86	146.6	0.05	8.5	0.05	8	0.03	5.2	3.39	0.06	1.77	0.03	8.56	0.15	20.60	0.35
12	0.34	59.6	0.08	13.4	0.72	126.5	0.04	6.9	0.04	6.87	0.02	4.2	14.00	0.25	3.04	0.05	10.40	0.18	23.30	0.41

N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulphur, Zn = zinc, Mn = manganese and B = boron.
[1] dw = dry weight, [2] fw = fresh weight.

Table 3. The complete mineral analysis (dry wet and wet analysis) for the 25 gram fruitlets from 12 orchards in the Goulburn Valley in the 2003 season

Orchard	N % dw[1]	N % fw[2]	P % dw	P % fw	K % dw	K % fw	Ca % dw	Ca % fw	Mg % dw	Mg % fw	S % dw	S % fw	Zn ppm dw	Zn ppm fw	Cu ppm dw	Cu ppm fw	Mn ppm dw	Mn ppm fw	B ppm dw	B ppm fw
1	0.42	65.7	0.09	13.6	0.89	141	0.06	8.8	0.06	8.84	0.04	7	5.29	0.08	1.39	0.02	4.14	0.07	25.90	0.41
2	0.55	100	0.08	15.2	0.86	15.72	0.06	11.7	0.07	12.05	0.04	8.1	6.29	0.11	1.63	0.03	3.49	0.6	16.10	0.29
3	0.75	110.5	0.09	13.3	1.01	149.2	0.05	7.5	0.07	9.89	0.04	6	8.88	0.13	0.82	0.01	5.97	0.09	20.10	0.3
4	0.51	93	0.10	17.5	0.90	165.9	0.07	12.7	0.07	13.59	0.04	8.2	4.97	0.09	2.58	0.05	4.38	0.08	17.40	0.32
5	0.51	85.7	0.09	14.7	0.89	150.5	0.08	12.7	0.07	12.02	0.04	6.6	4.05	0.07	2.45	0.04	3.73	0.66	22.00	0.37
6	0.53	82.3	0.09	13.6	0.90	138.8	0.06	8.7	0.06	8.2	0.05	7.2	7.69	0.12	1.67	0.03	3.64	0.06	19.80	0.31
7	0.64	125.9	0.09	16.9	0.87	173	0.05	10.1	0.07	13.48	0.05	9.1	13.40	0.27	2.90	0.06	4.64	0.09	19.00	0.38
8	0.38	71.6	0.08	15.5	0.84	159	0.06	10.6	0.05	10.04	0.04	7.8	4.04	0.08	2.11	0.04	3.37	0.6	22.30	0.42
9	0.36	59.8	0.07	11.8	0.64	105.9	0.07	11.1	0.06	9.6	0.04	6.9	14.80	0.24	1.10	0.02	4.06	0.07	13.20	0.22
10	0.35	56.5	0.08	13.6	0.94	152.3	0.07	10.8	0.05	8.09	0.04	6.3	5.74	0.09	1.53	0.02	4.07	0.07	30.10	0.49
11	0.56	87.6	0.08	13.2	0.87	137.3	0.07	10.6	0.06	10.09	0.04	6.9	4.36	0.07	2.17	0.03	3.78	0.06	19.20	0.3
12	0.59	96.1	0.09	14.6	0.92	149.2	0.06	9.1	0.06	9.92	0.05	8	8.11	0.12	1.94	0.03	4.59	0.07	20.40	0.33

N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulphur, Zn = zinc, Mn = manganese and B = boron..
[1] dw = dry weight, [2] fw = fresh weight.

Table 4. The complete mineral analysis (dry wet and wet analysis) for the 55 gram fruitlets from 12 orchards in the Goulburn Valley in the 2003 season

Orchard	N % dw[1]	N % fw[2]	P % dw	P % fw	K % dw	K % fw	Ca % dw	Ca % fw	Mg % dw	Mg % fw	S % dw	S % fw	Zn ppm dw	Zn ppm fw	Cu ppm dw	Cu ppm fw	Mn ppm dw	Mn ppm fw	B ppm dw	B ppm fw
1	0.18	28.9	0.08	12.1	0.74	116.5	0.05	7.5	0.05	7.54	0.06	8.7	4.05	0.06	0.84	0.01	3.47	0.05	23.10	0.36
2	0.22	39.9	0.06	11.8	0.74	136.8	0.05	8.3	0.05	8.86	0.06	10.5	5.63	0.1	0.64	0.01	2.46	0.05	15.10	0.28
3	0.35	59.3	0.06	9.4	0.66	112.8	0.04	6	0.05	8.16	0.04	6	4.32	0.07	0.54	<0.01	4.17	0.07	15.10	0.26
4	0.22	40.7	0.07	12.3	0.71	130.4	0.05	8.2	0.05	8.61	0.08	15.3	2.87	0.05	0.48	<0.01	2.62	0.05	15.30	0.28
5	0.22	33.5	0.07	10.3	0.73	113.9	0.05	8.4	0.05	7.8	0.04	6.3	3.17	0.05	0.51	<0.01	2.83	0.04	17.60	0.27
6	0.22	34.5	0.06	9.9	0.67	102.9	0.05	7.6	0.04	6.34	0.06	9.5	6.20	0.1	0.45	<0.01	2.85	0.04	16.30	0.25
7	0.29	58.8	0.06	11.6	0.79	162.1	0.04	7.6	0.05	10.62	0.04	7.8	7.85	0.16	0.48	<0.01	3.50	0.07	16.40	0.33
8	0.15	26	0.07	11.7	0.75	133.1	0.05	8.2	0.04	7.29	0.07	12.5	3.16	0.06	0.62	0.01	2.30	0.04	20.80	0.37
9	0.17	27.8	0.07	11.8	0.72	115.4	0.06	9.1	0.05	7.98	0.09	13.7	9.75	0.16	0.56	<0.01	3.46	0.06	23.70	0.38
10	0.13	21.7	0.07	11.6	0.79	132.9	0.05	8.4	0.04	6.55	0.06	9.4	4.31	0.07	0.22	<0.01	2.76	0.05	21.50	0.36
11	0.29	41.2	0.07	10.5	0.79	113.6	0.04	5.9	0.04	6.34	0.07	10.4	3.22	0.05	0.41	<0.01	2.63	0.04	16.80	0.24
12	0.25	38.9	0.06	9.8	0.72	110.8	0.04	6.6	0.05	7.22	0.06	8.7	5.33	0.08	1.20	0.02	4.02	0.06	17.50	0.27

N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulphur, Zn = zinc, Mn = manganese and B = boron..
[1] dw = dry weight, [2] fw = fresh weight.

Table5. The complete mineral analysis for medium size fruit from the 2nd harvest from 12 orchards in the Goulburn Valley in the 2002 season

Orchard	N % dw[1]	N % fw[2]	P % dw	P % fw	K % dw	K % fw	Ca % dw	Ca % fw	Mg % dw	Mg % fw	S % dw	S % fw	Zn ppm dw	Zn ppm fw	Cu ppm dw	Cu ppm fw	Mn ppm dw	Mn ppm fw	B ppm dw	B ppm fw
1	0.13	23.5	0.06	10.9	0.56	97.6	0.04	6.45	0.03	5.69	0.02	3.3	2.21	0.04	0.75	0.14	1.85	0.03	23.2	0.41
2	0.17	33.3	0.05	9.3	0.57	110.8	0.03	4.83	0.03	5.03	0.03	5.1	3.01	0.06	0.31	0.01	1.31	0.03	14.2	0.28
3	0.16	32.1	0.04	8.4	0.50	100.2	0.02	4.77	0.03	5.44	0.02	4.7	9.90	0.20	0.60	0.01	1.52	0.03	16.0	0.32
4	0.13	25.7	0.05	10.3	0.53	104.0	0.02	3.84	0.03	5.23	0.02	4.6	3.61	0.07	0.41	0.01	1.32	0.03	14.9	0.30
5	0.18	32.8	0.05	9.4	0.54	99.5	0.03	4.80	0.03	4.56	0.03	4.8	1.06	0.02	0.34	0.01	1.61	0.03	23.6	0.44
6	0.22	38.9	0.07	11.9	0.60	103.6	0.02	4.07	0.03	4.83	0.03	5.0	5.12	0.09	0.63	0.01	3.28	0.06	26.0	0.45
7	0.20	41.6	0.05	9.6	0.62	127.5	0.02	3.91	0.02	5.27	0.03	5.7	5.86	0.12	0.35	0.01	1.27	0.03	18.3	0.38
8	0.15	28.3	0.06	12.2	0.58	113.3	0.03	5.26	0.03	5.12	0.02	4.8	1.52	0.03	0.37	0.01	1.44	0.03	22.5	0.45
9	0.14	24.5	0.06	9.8	0.56	100.9	0.03	5.11	0.02	4.03	0.03	5.0	4.39	0.08	0.26	0.01	3.66	0.07	26.0	0.46
10	0.09	15.9	0.06	10.2	0.60	108.5	0.04	7.70	0.03	5.01	0.02	3.1	2.13	0.04	0.56	0.01	1.71	0.03	20.8	0.38
11	0.25	43.2	0.05	9.6	0.58	102.7	0.02	3.92	0.03	4.52	0.03	5.0	1.30	0.02	0.26	0.01	1.74	0.03	19.2	0.34
12	0.24	45.5	0.05	10.3	0.53	99.6	0.02	3.65	0.02	4.50	0.03	6.4	2.65	0.05	0.33	0.01	3.49	0.06	21.3	0.40

N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulphur, Zn = zinc, Mn = manganese and B = boron.
[1] dw = dry weight, [2] fw = fresh weight.

Table 6. The complete mineral analysis for medium size fruit from the 2nd harvest from 12 orchards in the Goulburn Valley in the 2003 season

Orchard	N % dw[1]	N % fw[2]	P % dw	P % fw	K % dw	K % fw	Ca % dw	Ca % fw	Mg % dw	Mg % fw	S % dw	S % fw	Zn ppm dw	Zn ppm fw	Cu ppm dw	Cu ppm fw	Mn ppm dw	Mn ppm fw	B ppm dw	B ppm fw
1	0.16	25.9	0.07	10.9	0.60	93.7	0.04	6.10	0.03	5.39	0.03	5.6	80.0	1.22	20.3	0.31	2.88	0.04	27.3	0.43
2	0.19	30.7	0.05	7.9	0.61	96.5	0.03	4.38	0.03	4.60	0.04	6.2	6.8	0.11	0.7	<0.01	2.14	0.03	17.0	0.27
3	0.28	44.1	0.06	9.1	0.65	103.8	0.03	4.55	0.04	5.91	0.04	6.3	5.3	0.08	0.6	0.0	2.97	0.05	19.2	0.30
4	0.18	28.4	0.06	10.2	0.65	100.8	0.03	4.23	0.03	4.96	0.04	6.3	5.6	0.09	0.1	<0.01	2.08	0.03	17.3	0.27
5	0.19	27.7	0.06	9.1	0.58	82.5	0.04	6.12	0.04	5.18	0.03	5.0	6.1	0.09	0.9	0.01	2.85	0.04	21.2	0.30
6	0.23	36.1	0.07	11.9	0.72	114.7	0.04	6.06	0.03	5.47	0.04	6.1	2.2	0.03	0.6	<0.01	2.61	0.04	24.3	0.38
7	0.24	38.8	0.05	7.7	0.59	94.0	0.02	4.08	0.03	4.96	0.03	5.6	7.7	0.12	1.0	0.01	2.35	0.04	21.5	0.34
8	0.20	31.3	0.06	9.9	0.66	103.6	0.03	4.60	0.03	4.38	0.03	5.1	5.0	0.08	0.3	<0.01	2.01	0.03	21.3	0.33
9	0.17	26.0	0.07	10.4	0.56	87.7	0.04	6.53	0.03	4.91	0.03	5.1	94.4	1.53	64.5	1.04	9.92	0.15	23.7	0.37
10	0.14	21.8	0.07	10.7	0.59	92.2	0.04	6.00	0.03	4.53	0.03	4.6	2.2	0.03	<0.0	<0.01	2.41	0.04	22.6	0.35
11	0.21	33.3	0.07	10.7	0.72	114.1	0.03	4.72	0.03	5.25	0.03	5.4	2.7	0.04	0.0	<0.01	2.13	0.03	26.3	0.42
12	0.24	38.0	0.05	8.7	0.64	99.6	0.03	4.72	0.03	5.19	0.05	7.3	7.7	0.12	1.2	0.01	3.31	0.05	22.7	0.35

N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, S = sulphur, Zn = zinc, Mn = manganese and B = boron.
[1] dw = dry weight, [2] fw = fresh weight.

Table 7. Soil samples were collected from each orchard on the 25th June 2002 and a complete nutrient analysis was done on the samples. The samples were taken from a 20 centimeter core sample, located central to two trees on the dripper line. Five samples were collected, one for each field replicate and a composite sample was used for the analysis.

Soil Analysis	Orchard											
	1	2	3	4	5	6	7	8	9	10	11	12
pH (H_2O)	7	7.6	5.7	7.0	6.3	6.9	6.8	7.5	7.6	6.9	7.3	6.8
Ph ($CaCL_2$)	6.6	7.1	5.1	6.2	5.5	6.2	6.3	7.0	6.9	6.3	6.8	6.1
Organic matter (%)	1.0	2.8	2.9	2.9	3.7	2.1	2.1	2.9	2.4	2.8	5.1	3.0
CEC (meq/100g)	6.1	11.5	8.0	12.6	9.3	8.6	8.6	12.5	11.2	8.4	12.7	12.0
EC (dS/m)	0.06	0.10	0.12	0.11	0.10	0.08	0.16	0.15	0.07	0.07	0.27	0.14
NO3-N (ppm)	5	4	15	2	7	6	15	4	3	1	48	15
Phosphorus [Olsen] (ppm)	25	24	30	14	10	34	7	13	28	7	22	51
Potassium (meq/100g)	0.42	0.59	0.5	0.52	0.56	0.59	1.26	0.68	0.42	0.57	0.85	0.84
Calcium (meq/100g)	4.04	0.11	6.00	8.79	6.85	6.71	5.73	10.08	9.37	5.93	9.50	9.52
Magnesium (meq/100g)	1.333	1.64	1.00	2.75	1.64	1.10	1.35	1.53	1.11	1.56	2.09	1.42
Sulphur (ppm)	6	7	8	10	11	6	26	19	6	6	18	15
Boron (ppm)	0.5	0.5	1.0	0.4	0.3	0.2	0.6	0.4	0.5	0.5	0.6	0.3
Copper (ppm)	3.9	3.6	1.2	2.2	13.4	5.6	8.3	6.4	7.6	1.0	23.5	6.8
Iron (ppm)	46	88	75	90	99	73	52	98	74	42	77	80
Manganese (ppm)	32	13	25	9	11	25	33	12	19	62	23	34
Zinc (ppm)	6.2	9.0	1.9	7.2	2.0	6.0	4.1	2.2	4.4	2.6	16.6	7.3
Aluminium (meq/100g)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sodium (meq/100g)	0.2	0.15	0.17	0.47	0.19	0.11	0.16	0.17	0.17	0.22	0.18	0.13
Chloride (ppm)	33.0	43.0	52.0	52.0	51.0	39.0	55.0	44.0	4.0	38.0	67.0	49.0
Ca base saturation (%)	66.5	78.9	71.2	69.7	73.5	78.1	66.9	80.5	83.8	70.9	74.6	79.4
K base saturation (%)	7	5.1	7.5	4.1	6.0	6.9	14.8	5.4	3.8	6.8	6.7	7.0
Mg base saturation (%)	22.0	14.2	17.9	21.9	17.6	12.8	15.8	12.2	10.0	18.7	16.4	11.9
Na base saturation (%)	3.3	1.3	2.1	3.7	2.0	1.2	1.8	1.3	1.5	2.6	1.4	1.1
Ca:Mg ratio	3.0	5.6	4.0	3.2	4.2	6.1	4.2	6.6	8.4	3.8	4.6	6.7
Texture	Sandy loam	Loam	Silty loam	Clay	Loam	Loam	Loam	Loam	Sandy loam	Clay	Loam	Loam
Colour	Yellow / brown	Yellow / brown	Brown	Brown	Yellow / brown	Brown	Brown	Yellow / brown	Brown	Brown	Yellow / brown	Brown

Table 8. Nutritional foliar spray records for orchard 1 used in the 2001, 2002 and 2003 seasons.

2000/2001 Date	Product	Spray volume rate (L/ha)[1]	2001/2002 Date	Product	Spray volume rate (L /ha)	2002/2003 Date	Product	Spray volume rate (L /ha)
25/10/2000	Calcium chloride[2]	11 kg	19/10/2001	Phoztrac	10	24/10/02	Stopit	10
31/10/2000	Calcium chloride	11 kg	19/10/2001	Caltrac	10	31/10/02	Phoztrac	5
4/11/2000	Calcium chloride	11 kg	24/10/2001	Phoztrac	10	31/10/02	Caltrac	5
13/11/2000	Calcium chloride	11 kg	24/10/2001	Catrac	10	7/11/02	Stopit	10
20/11/2000	Calcium chloride	11 kg	2/11/2001	Calcium chloride	11 kg	14/11/02	Phoztrac	5
29/11/2000	Seniphos	10	9/11/2001	Phoztrac	10	14/11/02	Caltrac	10
29/11/2000	Calcium chloride	9 kg	9/11/2001	Caltrac	10	22/11/02	Stopit	10
1/12/2000	Calcium chloride	10 kg	15/11/2001	Calcium chloride	11 kg	28/11/02	Stopit	10
7/11/2000	Calcium chloride	10 kg	27/11/2001	Calcium chloride	11 kg	12/12/02	Phoztrac	10
15/11/2000	Calcium chloride	10 kg	7/12/2001	Phoztrac	10	19/12/02	Stopit	10
22/11/2000	Calcium chloride	10 kg	7/12/2001	Caltrac	10	26/12/02	Stopit	10
10/01/2001	Stopit	5	21/12/2001	Phoztrac	10	26/12/02	Seniphos	10
19/01/2001	Stopit	5	21/12/2001	Caltrac	10	7/01/03	Stopit	10
10/05/2001	Bud builder	10 kg	8/01/2002	Stopit	5	7/01/03	Seniphos	10
10/05/2001	Safe N	15	21/01/2002	Stopit	5	23/01/03	Stopit	10
			12/02/2002	Hydromag	10	23/01/03	Seniphos	10
			18/05/2002	Bud builder	10 kg	14/02/03	Stopit	10
			18/05/2002	Safe N	15	14/02/03	Seniphos	10
						20/02/03	Stopit	10
						20/02/03	Seniphos	10
						3/03/03	Stopit	10
						3/3/03	Seniphos	10
						15/03/03	Stopit	10
						15/03/03	Seniphos	10
						24/03/03	Stopit	10
						24/03/03	Seniphos	10
						4/05/2003	Bud builder	10
						4/05/2003	Safe N	15

1. Litres per hectare except where noted the rate used was in kilograms.

2. Calcium chloride flakes.

17.2 Appendix B

The following fact sheets for minimising firmness loss in Pink Lady apples

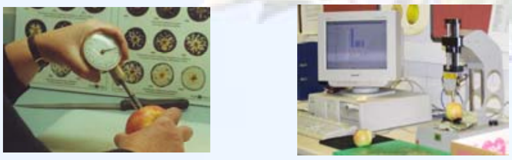
Minimising the risk of soft 'Pink Lady' apples after storage

Authors: **Ian Wilkinson and Christine Frisina, Department for Primary Industries Victoria**

Postharvest softening of 'Pink Lady' apple fruit is a serious problem for some orchards. Apple firmness is affected by seasonal conditions, orchard variability, crop load, tree vigour, nutrient status of the fruit at harvest, harvest maturity, storage and transport conditions and ethylene.

Firmness measurement

Fruit softening is typically assessed by a puncture test using a penetrometer. The penetrometer can be hand held or automated (Plate 1). Automated systems are a lot more expensive but they offer greater accuracy in being able to take out the operator error associated with hand held measurements.



A B

Plate 1. Examples of penetrometers used to measure apple firmness (A) hand held Effigi and (B) an automated system.

Maturity

There are many good publications describing tests for starch, firmness and ground colour that are used to predict the optimum maturity of apples at harvest (see for example Little and Holmes 2002, Chennell et al, 2002). Apples mature slowly then enter a more rapid ripening phase during the last 4 weeks before harvest. The degree of ripeness at harvest determines the length of the storage period. When the fruit shifts from the maturation phase to a ripening phase there is loss of starch and firmness from the flesh of the apple. Therefore, to maximise the firmness of fruit after storage requires the optimum firmness and starch levels in the fruit at harvest. Starch patterns are traditionally used to determine when to start harvesting apples. Starch plates are like "battery levels". The more energy left in the battery the longer the battery or apple, life. Plate 2 shows three typical starch patterns in iodine stained fruit suitable for:

A Long term CA storage (LTCA)
B Medium term CA storage (MTCA)
C Short term CA storage (STCA)

Optimum conventional CA for Pink Lady apples is 2.5% O_2 plus 1% CO_2

As a general rule, firm fruit before storage result in firm fruit after storage. Table 1 lists suggested firmness ranges for LTCA, MTCA and STCA. This rule must be taken with caution during drought years when fruit from some orchards can soften quicker in storage. It is important to measure the firmness of the fruit at the start, during and at the end of the harvest period, in order to determine its maximum storage potential when combined with the other harvest maturity indices.

Table 1. Firmness ranges at harvest for long, medium and short-term storage

Storage period	Firmness (kgf)
LTCA (7 months)	8.2 to 9.5
MTCA (5 months)	7.3 to 8.1
STCA (2 months)	6.7 to 7.2

The domestic market firmness standard is a minimum of 6.5 kgf. Apples can lose approximately 13% of the harvest firmness in 6 months and 27% in 9 months of conventional CA storage.

Growers are encouraged to use ultra low oxygen ULO storage (1.5% O_2) in place of conventional CA. In ULO storage fruit are likely to lose 15% of the harvest firmness in 9 months storage.

Temperature

Temperature before harvest plays an increasingly important role in storage longevity once the fruit has shifted from maturation to the ripening phase. In hot dry conditions the fruit is likely to ripen more quickly than in cooler conditions. To quickly slow down the rate of ripening and softening after harvest, the fruit needs to be cooled rapidly to 2°C or below starting no later than 12 hours after picking.

The storage room temperature needs to be 0°C. If the room has hot spots as high as 3°C fruit will soften faster. The stacking pattern of the bins is important because poor air-flow patterns in the room can lead to hot spots.

Ethylene

Ethylene is the apple's natural ripening hormone. A sudden increase in the fruit ethylene levels indicates the start of the ripening process. This results in a rapid increase in respiration and rapid softening of the fruit.

A B C

Plate 2. Starch patterns in Pink Lady apples suitable for long term storage (A), medium term storage (B) and short-term storage (C).

Ethylene continued:

Keeping ethylene levels below 0.5 parts per million (ppm) in the storage room during filling and for the first two months of storage can reduce ethylene production by the fruit and ethylene action on fruit softening. To achieve the ethylene levels needed a catalytic ethylene scrubber should be installed. Low oxygen storage at 1.5% also suppresses ethylene production and action.

SmartFresh™ is a gas that blocks ethylene action in the fruit. It is applied to the fruit shortly after harvest. Indications are that it is likely to be as effective as an ethylene scrubber. Fruit firmness is significantly improved after long term storage in air and CA. SmartFresh™ treated fruit can be 0.5 to 1.5 kgf firmer after medium to long term storage subject to orchard and seasonal variations.

Colouration

The minimum colour specification for Pink Lady apples is 40 to 50% bright red blush. For some orchards colouring of the fruit to this level is a problem. Waiting too long for colour to develop can results in over mature fruit at harvest and soft fruit outturns. Reflective mulches increase the level of light inside the tree canopy and make it possible to colour fruit earlier. Reflectors have a major effect on colouring and a minor effect on ripening rate. Potentially, earlier colouring of the fruit could result in fruit being picked closer to optimum maturity. Growth retardants may also assist colour development by retarding shoot growth.

Nutrition

Mineral levels and mineral ratios in the fruit have a major effect on fruit firmness. Low levels of calcium and phosphorus and high levels of nitrogen and potassium can lead to soft fruit outturns (Table 2).

Table 2. The low or high and optimum levels of calcium, phosphorus, nitrogen and potassium in fruit at harvest.

Nutrient	Low or high levels Percentage dry weight l	Optimum levels Percentage dry weight
Calcium	0.023	0.041
Phosphorus	0.04	0.08
Nitrogen	0.32	0.18
Potassium	1.08	0.70

Mineral balance also affect fruit firmness and the ideal mineral ratios are: Ca : N (1:4.5), Ca : P (1 : 2.2), Ca : K (1:30).

The nutritional status of the fruit at harvest must be maintained in relation to the crop load and tree vigour. Sustaining two consecutive years of high crop loads (11-12 fruit per centimeter butt) requires a low Ca / N ratio [1 : 4.5], with reduced tree vigour to ensure optimal levels of Ca and N in the fruit at harvest. It is advisable to have 50 gram fruitlets analysed in the Spring for their nutrient status to gauge if nutritional correction is required. Major deviations from the optimum standards will increase the risk of soft fruit. For more detailed information refer to the publications listed below or consult your local industry adviser.

High nitrogen levels in the fruit can increase the rate of softening. However, nitrogen is important for yield and must be maintained at an adequate level to ensure good tree health. The nitrogen to calcium ratio needs to be low (4.5 : 1).

Nitrogen in the deficit range can be corrected in one season but calcium in the deficit range may take three to four years to correct. Therefore, it is important to have fruitlets analysed early in the season to allow time to make any corrections in the nutritional balance of the fruit. P deficiency may take more than one season to correct.

The best results from foliar application are achieved when applied to trees not under too much stress. Sprays should be applied when humidity is high. Temperatures should be less than 25°C, the light intensity low and the young foliage-fully turgid. The mixture should have a slightly acid pH and the tree canopy should be thoroughly wetted requiring 1000 – 2000 L/ha.

By 50 days after full bloom (DAFB) the cell division phase of the fruit development is complete. This is the critical time for getting foliar applied nutrients into the fruit. Growers need to apply at least 4 calcium sprays during the 50 DAFB to have much effect on firmness. High P levels in the fruit can assist in earlier colour development and thus earlier harvest times if the weather conditions are not too hot.

To maximise the benefits of foliar sprays in Spring, it is important that the orchard is well watered. The soil should be at full capacity in Winter to ensure the tree is not under stress in the Spring.

Soil and leaf samples should be analysed for mineral deficiency in the Spring. If levels are deficient in the soil, tree or fruitlets consult your local nutritional consultant to prepare a foliar, soil fertiliser and fertigation program to best correct the nutritional imbalances.

Tree health

A healthy tree is essential to obtaining firm fruit. Stress caused by nutritional deficiency or lack of water will affect fruit firmness. In addition, soil pathogens such as *Phytophora* will affect tree roots thus reducing water and nutrient uptake.

Conclusions

Prevention is better than correction for soft fruit outturns. Therefore, the more comprehensive the historical records on pre and post harvest management data for a specific orchard the greater the chances of avoiding soft fruit after storage. Over mature fruit at harvest is a major factor contributing to soft fruit outturns. Growers naturally want to maximise the tonnage of fruit from an orchard. To do this they are tempted to delay picking and therefore, the fruit is harvested over mature. This makes it even more important to know the exact maturity of the fruit going into storage to avoid storing the fruit too long.

Removing ethylene from the storage environment is a key to obtaining firm fruit. Measures that reduce ethylene production will significantly reduce the risk of soft fruit outturns. These measures require the use of ethylene scrubbers or treatments that negate the adverse effects of ethylene.

This article presents an overview of factors that may contribute to soft fruit outturns. However, there is no single recipe for preventing soft fruit outturn. A number of factors may be involved and these often vary considerably between orchards.

Further information

Further information on preharvest and postharvest factors affecting softening of apples can be obtained from:

- Wilkinson R I, Frisina C, Franz P and Brown G (2004). Tracking Pink Lady apple firmness. Horticulture Australia Project HAL AP 01036, Final report.

- Little C R and Holmes R J (2000). Storage technology for apples and pears (Ed. Faragher, J) Department of Primary Industries, Victoria, Highway Press P/L, ISBN 0 7311 4466 X, pp. 112-152

- Chennell A, Bates V and Williams D (2002). Apple Maturity Management Training Workshop Manual. Department of Primary Industries, Victoria, pp. 1-34.

- Johnston J W, Hewett E W and Hertog M L A T (2002). Postharvest softening of apple (*Malus domestica*) fruit: a review. New Zealand Journal of Crop and Horticultural Science, **30**:145-160.

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Minimising the risk of soft 'Pink Lady' apples arriving in the UK

Authors: **Ian Wilkinson and Christine Frisina, Department for Primary Industries Victoria**

The firmness standard for apples arriving in the UK is higher than that required for the Australian domestic market. Importers in the UK want Pink Lady apples to have a minimum average fruit firmness of 7 kgf and will accept 10% of the fruit with 6.5 kgf to 6.9 kgf.

Apples enter a more rapid ripening phase during the last 4 weeks before harvest. The degree of ripeness at harvest determines the length of the storage period. Ripeness is controlled by ethylene the plants natural ripening hormone. Control of ethylene is a key to minimising the problem of soft fruit arriving in the UK

The Pink Lady cultivar produces high levels of ethylene. The postharvest effects of ethylene on fruit softening must be minimised by 1) rapid cooling, 2) using low oxygen storage, 3) scrubbing ethylene in the storage atmosphere during room loading and storage to less than 0.5 parts per million (ppm) to make sure the internal concentration of the fruit is kept at less than 1 ppm or 4) using SmartFresh™ a gas that blocks ethylene action in the fruit by applying it to the storage atmosphere shortly after harvest.

The export standard for colour is 50% of the fruit surface exhibiting a bright pink blush. In the past, fruit has been picked over mature due to waiting for more colour to meet the domestic market standard which was 60% blush. The colour standard for the domestic market has been reduced to 40 to 50% blush. Therefore, fewer fruit should be picked over mature as a result of waiting for colour.

Soft fruit outturns in the UK have resulted from sending over mature fruit that had been air stored for 2 to 3 months before shipping. Fruit destined for export should not be air stored longer than 6 weeks. However, soft fruit outturns have also occurred with CA stored fruit picked at the domestic harvest, after 4 months CA. Fruit picked at optimum maturity based on starch and firmness has a much greater chance of arriving firm and within specification (see fact sheet Wilkinson R I and Frisina C (2004) for more information on maturity testing).

Ideally, Pink Lady apples should be picked with the starch pattern shown in Plate 1A for long-term storage, up to late October. However, keeping in mind that the UK importers only want Australian Pink Lady apples up to mid October, it may be possible to pick export fruit at starch Plate 1B. These fruit are suitable for medium term CA storage. However, it is always preferable to pick fruit closer to Plate 1A.

A

B

Plate 1. The optimum starch plates for long term CA storage (A) and the typical starch plates suitable for medium term CA storage (B).

Table 1. The minimum firmness requirements for Pink Lady apples at harvest, before shipping and on arrival in the UK

Firmness (kgf)		
At harvest	Pre-shipping	On arrival in the UK
8.5	7.5	7.0

Pink Lady apples can lose 0.5 to 1.0 kgf in storage and approximately 0.5 kgf during shipping. Therefore, fruit destined for export need to be picked with a firmness of 8.5 kgf (Table 1). It is important to know the firmness of the fruit at the beginning and the end of harvest. The fruit firmness at packing needs to be 7.5 kgf with no more than 10% in the range 7.0 to 7.4 kgf to minimise the risk of soft fruit.

SmartFresh™ an inhibitor of ethylene action, helps keep apples firm. Firmness measurements in the UK on 3 years of experimental shipments found SmartFresh™ treated fruit were 0.5 to 2.0 kgf firmer than the untreated fruit.

Maintaining the cool chain is essential to maintaining fruit firmness. Therefore, the time the fruit is on the packing floor needs to be minimal and the fruit core temperature must be down to a carriage temperature of 0°C before the fruit is loaded into the container. Refrigerated containers are designed to maintain fruit core temperatures not to cool down the core temperature of the fruit. Hot spots as a high as 4°C can occur in some shipping containers. Fruit located in the hot spots from some orchards are able to maintain acceptable levels of firmness whereas others cannot. Why fruit from some orchards can withstand higher temperature during shipment while fruit from other orchards soften is not readily understood.

Mineral levels and mineral ratios in the fruit have a major effect on fruit firmness. Low levels of calcium and phosphorus and high levels of nitrogen and potassium in the fruit can lead to soft fruit outturns (Table 2). Growers need to aim for optimum levels of minerals in the fruit to minimise firmness loss.

Table 2. The low and optimum levels of calcium, phosphorus, nitrogen and potassium in fruit at harvest.

Nutrient	Low or high levels Percentage dry weight	Optimum level Percentage dry weight
Calcium	0.023	0.041
Phosphorus	0.04	0.08
Nitrogen	0.32	0.18
Potassium	1.08	0.70

The mineral levels are taken from Colin Little's 'Mineral assessment on apple fruit taken at optimum maturity for long term 'CA'storage' see Wilkinson R I, Frisina C, Franz P and Brown G (2004).
Mineral balance also affects fruit firmness and the ideal mineral ratios are: Ca : N (1:4.5), Ca : P (1 : 2.2), Ca : K (1:30). (Little and Holmes, 2000. p 100).

The nutritional status of the fruit at harvest must be maintained in relation to the crop load and tree vigour. Sustaining two consecutive years of high crop loads (11-12 fruit per centimeter butt) requires a low Ca / N ratio (1 : 4.5), with reduced tree vigour to ensure optimal levels of Ca and N in the fruit at harvest. It is advisable to have 50 gram fruitlets analysed in the Spring for their nutrient status to gauge if nutritional correction is required. Major deviations from the optimum standards will increase the risk of soft fruit. For more detailed information refer to the publications listed below or consult your local nutritional adviser.

Conclusion

Postharvest softening of 'Pink Lady' apple fruit arriving in the UK is a serious problem for some orchards. Therefore, planning for the production of export fruit begins at flowering when deciding the level of thinning. The next step is knowing the nutrient status of the fruitlets and whether or not nutrient correction sprays are needed. Early sample fruitlet analysis enables sufficient time to apply corrective sprays during the 50 days after full bloom which is the period when cell division is taking place in the developing fruit. The next step is to harvest the fruit as close as possible to optimum maturity. Ethylene has a major effect on fruit softening during storage and transport. Therefore, ethylene levels must be controlled by the use of low temperature, low oxygen conditions and ethylene scrubbers or SmartFresh™. Finally, the cool chain must be maintained at all times. The firmness of the fruit must be measured after storage and deciding the risk of the fruit being too soft on arriving in the UK must be made using the guidelines presented in this fact sheet.

Further information

Further information on Postharvest softening of apples can be obtained from:

- Wilkinson R I, Frisina C, Franz P and Brown G (2004). Tracking Pink Lady apple firmness. Horticulture Australia Project HAL AP 01036, Final report.
- Little C R and Holmes R J (2000). Storage technology for apples and pears (Ed. Faragher, J) Department of Primary Industries, Victoria, Highway Press P/L, ISBN 0 7311 4466 X, pp. 112-152.
- Chennell A, Bates V and Williams D (2002). Apple Maturity Management Training Workshop Manual. Department of Primary Industries, Victoria, pp. 1-34.
- Johnston J W, Hewett E W and Hertog M L A T (2002). Postharvest softening of apple (*Malus domestica*) fruit: a review. New Zealand Journal of Crop and Horticultural Science, **30**:145-160.

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