Preventing rapid ripening of Pink Lady and Fuji Apples

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Preventing Rapid Ripening of Pink Lady and Fuji apples

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Executive Summary

- Fuji apples are susceptible to rapid ripening if stored in air at low temperatures. The best way to prevent rapid ripening is to store fruit under CA conditions.

- Pink Lady apples are not prone to rapid ripening but storage life is compromised if harvest maturity is late and cool room temperatures are higher than 0°C for both air storage and CA (2% O₂ and <1% CO₂).

- The important message for apple growers is that control of cool room temperatures is essential. This is true for both varieties of apples. The storage life of both Pink Lady and Fuji apples is compromised if the cool room temperature is 3°C rather than 0°C.

- A 3°C difference in temperature may seem small but it has a significant effect on the out turn quality of the fruit. This preliminary results highlights the importance of cool room management for ensuring postharvest fruit quality.

- Flesh browning can be induced in Pink Lady apples by storing them in atmospheres of high CO₂. Although the symptoms are not the same as "commercial" flesh browning. Symptoms of flesh browning induced by anaerobic respiration seem to be similar to that seen under commercial conditions.

- The Aweta Acoustic firmness tester can differentiate between Pink Lady apples with and without flesh browning. This could be a non-destructive method for separating damaged fruit before packing and shipping.
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1. Introduction

The Australian apple industry is one of Australia's major horticultural industries, valued around $360 million in 2000 and the Australian export of apples is currently worth $36.5 million (AHC, 2000). The industry does have potential to expand with the increased production of new varieties like Pink Lady and Fuji. The key for Australian producers is to produce quality fruit which maintains its crispness right through to the final consumer.

It is important that air stored or CA stored apples have a reasonable shelf life on reaching the wholesale market. Consumers who purchase floury apples are reluctant to purchase apples again in their next shop.

Pink Lady and Fuji apples store well. However research has shown that Fuji and Lady Williams apples (a parent of Pink Lady) are induced to ripen rapidly if they are chilled for a month or more at 0°C and then returned to ambient conditions (Jobling and McGlasson, 1995). Rapid ripening seriously reduces the consumer shelf life of these varieties. The fruit may be of excellent quality straight after removal from storage, but on arrival at the wholesale markets, or the supermarket the prized crispness and flavour, so important for quality has been lost.

This project looked specifically at the pattern of ethylene biosynthesis. Ethylene production is stimulated by chilling in fruit of some cultivars of apples, citrus, cucumbers and pears (Jobling et al., 1991; Knee 1993). Chill-induced ethylene production is associated with unacceptable symptoms of chilling injury to citrus and cucumbers; however in pears it stimulates uniform, high quality ripening, which is not achieved if pears are left to ripen naturally (Blankenship and Richardson, 1985). Some apple cultivars are also chilling sensitive. For example Jonagold, Elstar and Bramley's seedling all store better at temperatures above 1°C (Van Schaik, 1998; Goffings, 1990). This project aimed to determine if chill induced ripening could be prevented by storing the fruit at 3°C rather than 0°C.

Storage temperature is especially critical during transport to more distant markets. Here the shelf life after transport is critical as the fruit may still have to travel reasonable distances to reach consumer markets. If consumers receive poor quality, floury fruit, then the demand for repeat sales will be stifled. This research project aimed to confirm whether Pink Lady and Fuji apples were chilling sensitive and to establish storage regimes that would prevent the development of rapid ripening. The project was carried out over two seasons, 2001 and 2002. The fruit from the 2001 season were from Orange and for 2002 were from Batlow, NSW.
2. **Materials and Methods**

2.1 **Year 1 – 2001 season.**

The fruit was harvested from Peter McClymont’s orchard “Coilsfield”, Orange NSW. The Fuji apples used were Nagafii 2 grown on M6 rootstocks with M9 inter-stems on a 3-wire trellis. The Pink Lady Apples were on M9 rootstocks also on a 3-wire trellis. The trees were 4 years old.

**Fuji Maturity**

Three harvests of Fuji apples were made; 2/4/01, 11/4/01 and 20/4/01. From the starch index data these harvests would represent early, optimum and late in terms of maturity for CA storage. Table 1 summarises the main maturity parameters. As would be expected the starch score increases with later harvests as does the level of %TSS and internal ethylene and the firmness decreased.

<table>
<thead>
<tr>
<th>Harvest Date</th>
<th>2/4/01</th>
<th>11/4/01</th>
<th>20/4/01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Ethylene (ppm)</td>
<td>0.1</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>Starch Index*</td>
<td>2.27</td>
<td>2.37</td>
<td>4.35</td>
</tr>
<tr>
<td>Firmness</td>
<td>8.35</td>
<td>7.83</td>
<td>7.79</td>
</tr>
<tr>
<td>%TSS</td>
<td>13.48</td>
<td>14.55</td>
<td>14.6</td>
</tr>
</tbody>
</table>

* Little and Holmes (2000). Figure 4.11 - Starch Patterns – Concentric Type, p 149.

**Pink Lady Maturity**

Pink Lady apples were harvested on the 20/4/01 and the 4/5/01. Only two harvests were made due to the harvest window being around the Easter/Anzac day period. Table 2 summarises the main maturity parameters. Fruit from harvest 1 would have been suitable for CA storage and fruit from harvest 2 would have been suitable for immediate sale on the fresh market.

<table>
<thead>
<tr>
<th>Harvest Date</th>
<th>20/4/01</th>
<th>4/5/01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Ethylene (ppm)</td>
<td>0.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Starch Index*</td>
<td>1.55</td>
<td>3.5</td>
</tr>
<tr>
<td>Firmness</td>
<td>9.8</td>
<td>6.8</td>
</tr>
<tr>
<td>%TSS</td>
<td>12.9</td>
<td>18.0</td>
</tr>
</tbody>
</table>

* Little and Holmes (2000). Figure 4.10 - Starch Patterns – Concentric Type. p 148.

**Storage Trial**

Year 1 – The storage trial was carried out at Sydney Postharvest Laboratory, North Ryde, NSW. The fruit were stored in air at 0, 3, 10 or 20°C as well as samples being stored in controlled atmosphere storage (CA) at 2% oxygen and < 0.1% carbon dioxide and either 0 or 3°C. The CA system was a flow through system which used 60 litre plastic drums as the storage unit and the flow rate of airflow was 100 mL/minute.
Fruit Analysis

The fruit in air were assessed after 0, 4, 7, 14 and 21 days. The fruit in CA storage were assessed after 3 and 6 months storage and then 0, 4, 7, 14 and 21 days at 20°C. At each removal the following parameters were measured on 10 fruit per treatment.

Internal ethylene was measured by taking a 2 mL sample of air using a needle and plastic syringe form the core cavity of each fruit. A 200 μL sample of the gas was analysed by gas chromatograph (Flame ionisation detector, Shimadzu GC – 17A, GS-Q column J & W Scientific with helium as the carrier gas). The limit of detection was 0.1 μL/L. Fruit firmness was measured using an Effegi penetrometer with an 11 mm tip mounted in a drill press.

The level of total soluble solids was measured using a bench top refractometer and the starch index was rated using the starch chart for Fuji and Pink Lady as illustrated by Little and Holmes (2000).

For the assessment of the fruit from CA storage all harvests were removed on the same day in order that a direct comparison between harvest dates could be made. The fruit were removed from CA storage after 3 and 6 months and then left at room temperature (20°C) to be assessed after 0, 4, 7 and 14 days.

After 3 months storage the fruit were assessed for internal ethylene levels, flesh firmness and TSS levels after 6 months the background colour was also assessed using a 4 point rating scale with 1 being green and 4 being yellow.

2.2  Year 2 – 2002 season.

The fruit for the second years work came from Sheen’s orchard in Batlow. The results from 2001 showed that Pink Lady apples were not chilling sensitive and did not suffer from rapid ripening. Therefore in the 2002 season the experiments focused
on the induction of ethylene production in Fuji apples and the induction of flesh browning if Pink Lady apples. The induction of flesh browning experiments for Pink Lady apples will be valuable as a lead into project AP02009 Understanding the flesh browning disorder of Pink Lady apples.

**Rapid Ripening of Fuji apples**

The second years work focused on the mechanism of induction of rapid ripening. Fruit were harvested on the 5th April 2002. The fruit were stored at 0, 3, 10 and 20°C. The fruit were assessed at weekly intervals during storage. The fruit were removed after 30 days in storage and assessed after 0, 4, 7, 14 and 21 days at 20°C.

The same quality parameters were assessed as in 2001 with the addition of assaying the activity of ACC Oxidase. ACC Oxidase activity was determined according to the procedures of Jobling and McGlasson (1995). ACC Oxidase activity (the ability to convert ACC to ethylene) was expressed as nL per g per h.

**Induction of Flesh Browning in Pink Lady apples**

Pink Lady apples were collected on the 11th April from an orchard in Tumut. These apples had internal browning which was suspected to be related to symptoms of boron deficiency. Samples of fruit with varying degrees of symptoms were collected and brought back to Sydney Postharvest Laboratory for analysis. The quality, acoustic firmness (AWETA Pty Ltd) and mineral composition of the fruit were assessed.

Another sample of fruit was harvested from Batlow on the 23rd of April and was sent overnight to the Sydney markets where they were collected and brought to Sydney Postharvest Laboratory. The fruit were placed in different atmospheres to determine if the symptoms of flesh browning could be induced with either low oxygen or high CO2 during storage. Fruit were placed in either 100% nitrogen or 20% CO2 plus air at either 0 or 20°C. A control sample of fruit was kept at 0°C in air.

The fruit were removed at 2 weekly intervals for 6 weeks and the level of internal browning was measured as well as the acoustic firmness of each fruit. This was done in an effort to determine if flesh browning could be detected via this non-destructive method.

**Statistical analysis**

Data from all experiments were subjected to an analysis of variance in a linear model (GLM) using Simstat for Windows version 2.0 (Provalis Research). The means where appropriate were compared using Waller-Duncan's Bayesian k-ratio LSD at K=100 (Steel and Torrie, 1980). If the difference of the means is greater than the KLsd value then the means are significantly different (P = 0.05).
3. Results and Discussion

3.1 Rapid Ripening of Fuji apples

The internal ethylene levels of the fruit at 20°C correspond to the levels found in the fruit after harvest. Fuji apples typically have low levels of ethylene production in comparison to other varieties (Figs 1 – 3).

After storage in air at 0, 3 and 10°C the level of internal ethylene was significantly higher than the level after harvest. This result was true for all 3 harvest dates. This result indicates that later harvested fruit are just as susceptible to rapid ripening as immature fruit.

The results also show that the induction of rapid ripening is not prevented by storage at warmer temperatures. It may be that Fuji apples respond to low temperatures in a similar way to stonefruit with temperatures from 2 – 10°C actually being more damaging than storage at 0°C or above 10°C. This may be due to a differential response to temperature by some of the enzymes involved in ethylene metabolism. Other researchers have found that this reaction is sensitive to temperatures < 12°C (Apelbaum et al, 1981; Ben-Arie et al., 1982). More specific work has shown that ACC to accumulates at low temperatures producing a burst of ethylene production on
warming to room temperature (Jobling et al., 1991; Larrigaudiere and Vendrell, 1993).

The results for the induction of rapid ripening become clearer in 2002. The induction of rapid ripening is a function of both temperature (Fig 4 and 5) and time (Fig 6 and 7). There is a highly significant effect of both, treatment and time as well as a significant first order interaction between treatment and time for internal ethylene and ACC oxidase activity.

The results from 2002 show that storing Fuji apples at 0, 3 and 10°C increases internal ethylene and ACC oxidase activity to levels higher than those after harvest (Fig 4 and Fig 5). However the effect is not simply a function of temperature as fruit left longer at 20°C after harvest eventually produced as much ethylene as those after storage.

An interesting result is seen with the comparison of the ACC oxidase activity of the fruit held at different temperatures (Fig 7). The pattern of ACC oxidase activity for the fruit stored at 10 and 20°C follows the same pattern as the level of internal ethylene. This is not the case for the 0 and 3°C treatments. The level of ACC oxidase activity is significantly higher in the fruit stored at 0°C then the corresponding level of internal ethylene. This is also the case for the fruit stored at 3°C but the difference is not so large. These results support those reported by Jobling and McGlasson (1995) earlier. The response to chilling appears to be linked to the activation of ACC
oxidase.

The induction of ethylene production also has significant commercial implications. Fruit stored at 0 and 3°C were significantly softer than fruit stored at 20 and 10°C (Figures 8 and 9). Storing fruit at 20 and 10°C for long periods is not a solution to this problem as the shelf life is lost as a result of other ripening changes such as yellowing of the background colour.

![Fig. 8. Changes in firmness of Fuji apples during storage at different temperatures 2002.](image1)

![Fig. 9. Changes in the firmness of Fuji held at 20°C after storage 2002.](image2)

The commercial solution to the induction of rapid ripening is not to store Fuji apples at warmer temperatures, 3°C as hypothesised but to store fruit, even for short periods in CA (2% O2 and <1% CO2). The following section illustrates how rapid ripening is prevented by storage in CA.

3.2 CA storage trial for Fuji apples assessed after 3 and 6 months

After 3 months in CA storage there was no significant differences between the levels of internal ethylene for any harvest at either temperature (Fig. 10). It is important to note however that the average level of internal ethylene for all treatments after 14 days at 20°C was much lower (-0.1, Fig 10) than the level after harvest (1.7, Fig 6). CA storage seems to limit the ability of the fruit to produce ethylene on return to air at 20°C. The low oxygen may inhibit the accumulation of ACC, which is the precursor to ethylene that accumulates in Fuji apples when stored in air at low temperature (Jobling and McGlasson, 1995).

![Fig. 10 Internal ethylene levels of Fuji apples after 3 months storage in CA at either 0 or 3°C (H1 = harvest 1, H2 = harvest 2 and H3 = harvest 3) 2001.](image3)
After 6 months in CA storage fruit stored at 0°C and 3°C had low levels of ethylene production (Fig 11), lower than the levels produced after storage in air (Fig. 6). However the fruit stored at 3°C did produce significantly more ethylene after 14 days in storage than fruit stored at 0°C.

![Graph showing ethylene production](image1)

Fig. 11 Internal ethylene levels of Fuji apples after 6 months storage in CA at either 0 or 3°C (H1 = harvest 1, H2 = harvest 2 and H3 = harvest 3) 2001.

The results show that chill induced ripening does not occur under CA conditions. Low oxygen levels inhibit the ethylene biosynthesis pathway and as a result rapid ripening is not induced on return to ambient conditions.

This is an important result as it shows the benefit of storing fruit under CA conditions even for short periods. Storing Fuji apples under CA conditions prevents the development of rapid ripening and therefore significantly improves the shelf life of the apples after removal from storage compared to storage of fruit in air.

There were no significant differences in the level of firmness on removal from CA after 3 or 6 months.

![Graph showing flesh firmness](image2)

Fig. 12 Flesh firmness of Fuji apples after 6 months storage in CA at either 0 or 3°C (H1 = harvest 1, H2 = harvest 2 and H3 = harvest 3).
There was however, an important difference in the rate of yellowing of the background colour of Fuji apples (Fig. 10). There was a difference between the background colour score as a result of treatment and time. All harvest at 0°C had a greener background colour after 14 days at 20°C than those stored at 3°C. For consumers this is an important quality parameter, as shoppers must "buy with their eyes". Fruit with a greener background colour, are regarded by most consumers as fresher than those that have yellowed. Therefore CA storage at 0°C provides better quality fruit than CA storage at 3°C.

![Graph showing changes in background colour of Fuji apples after 6 months storage in CA at either 0 or 3°C (H1 = harvest 1, H2 = harvest 2 and H3 = harvest 3).](image)

**Fig 10.** Changes in background colour of Fuji apples after 6 months storage in CA at either 0 or 3°C (H1 = harvest 1, H2 = harvest 2 and H3 = harvest 3).

### 3.3 Practical Outcomes for Fuji apples

- Fuji apples are susceptible to rapid ripening if stored in air at low temperatures. The best way to prevent rapid ripening is to store fruit under CA conditions.

- The important message for apple growers is that control of cool room temperatures is essential. The storage life Fuji apples is compromised if the cool room temperature is 3°C rather than 0°C.

- A 3°C difference in temperature may seem small but it has a significant effect on the out turn quality of the fruit. This preliminary results highlights the importance of cool room management for ensuring postharvest fruit quality.
3.4 Induction of Rapid Ripening in Pink Lady apples

Pink Lady apples have a typical climacteric rise in ethylene production (Fig. 11). The rise in internal ethylene has a similar pattern to the change in starch index. Harvest 1 (20th April 2001) was ideal for controlled atmosphere storage as ethylene production did not begin until after day 4. This would mean that preclimacteric fruit would have been placed in CA storage. The average starch index of fruit harvested at this time was 1.5 which is the recommended score for fruit being placed into long term CA storage (Little and Holmes, 2001).

Harvest 2 was well suited to the fresh market as ethylene production and ripening had begun at harvest and the starch index was also high at 3.5. The sweetness and flavour of fruit harvested at this maturity would be developing during transport and marketing. This would mean that the final consumer would receive a tasty, quality apple.

![Fig 11. Changes in internal ethylene levels of Pink Lady apples after harvest in 2001.](image1)

![Fig 12. Changes in the starch index of Pink Lady apples after harvest in 2001.](image2)

It is important to note that there is a good correlation between the starch index and the level of internal ethylene. This means that the starch index is a very useful maturity parameter for this variety.

Fruit from the two harvests were placed in cool rooms in air at 0, 3 or 10°C in order to determine if they were prone to rapid ripening. The level of internal ethylene of fruit from both harvests at all temperatures was quite high on removal from storage (Fig. 13). Although fruit stored at 0°C were significantly lower than the other temperatures.

This shows that storage at low temperature in air does not induce rapid ripening or inhibit ripening, although 0°C does slow the process. The data for both harvests shows that the warmer the storage temperature the higher the level of ethylene production.

This result also has practical consequences. The results for the changes in flesh firmness show that fruit from harvest 2 soften more than fruit from harvest 1 as they were more mature when placed in storage (Fig. 14). The results also show that fruit stored at 0°C were firmer than fruit stored at the warmer temperatures.

These results show that Pink Lady apples are not susceptible to rapid ripening. However maturity at harvest is a key factor in determining storage life and quality.
Fig 13. Changes in internal ethylene levels of Pink Lady apples after 1 month storage in air at different temperatures.

Fig 14. Changes in firmness of Pink Lady apples after 1 month storage in air at different temperatures.

Practical Implications

The message for apple growers and cool room operators is that maturity and temperature management are critical for ensuring storage life and quality of Pink Lady apples. The fruit may appear in good condition on removal from storage but that quality is quickly lost as the fruit warm to room temperature. Ideally air stored fruit should be transported and keep at 0°C throughout marketing and retail display to ensure there is some remaining shelf life for the consumer. This data also puts in doubt the practise of exporting Pink Lady in refrigerated containers, as the shelf life on arrival at the destination will be short particularly if the fruit are harvested late.

Another important factor is cool room temperature management. Variations in temperature of only a few degrees can cause a significant reduction in shelf life of Pink Lady apples.
3.5 CA storage trial for Pink Lady apples assessed after 3 and 6 months.

The results from the 3 month removal from CA storage show that fruit stored at 0°C actually had higher ethylene levels on removal from storage than the fruit at 3°C (Fig. 15). However, all fruit reach similar levels after 7 days at 20°C. The results for loss of firmness and change in background colour however, indicate that 0°C is a better storage temperature than 3°C as fruit quality is not lost as quickly.

![Fig 15. Changes in the level of internal ethylene of Pink Lady apples after removal from 3 months CA storage and 14 days at 20°C.](image1)

Figure 16 illustrates the results for the loss of firmness. Fruit from harvest 2 stored at both 0 or 3°C were softer and lost firmness more quickly than fruit from harvest 1.

This effect of fruit maturity is well known but is sometimes overlooked, as growers try and leave the fruit on the tree as long as possible in an effort to gain maximum pink blush for this variety. This result shows that fruit aimed for export by sea freight in air must be harvested at the correct maturity if fruit quality is to be maintained during transport. Consumers prefer crisp apples and so fruit harvested pre-climacteric, before ethylene production has begun, are more likely to have an acceptable shelf life on arrival compared to fruit harvested later.

![Figure 16. Changes in flesh firmness of Pink Lady apples after removal from 3 months CA storage and 14 days at 20°C.](image2)
Another important quality parameter is the change in background colour from green to yellow. Consumers regard fruit with a greener background colour as fresher than one that has yellowed. Figure 17 shows that fruit from Harvest 1 maintained a greener background colour longer than fruit from harvest 2. Fruit from harvest 2 stored at 3°C were yellow after 7 days at 20°C. This would indicate that late harvested fruit stored at a higher temperature do not have enough shelf life on removal from storage to reach the point of sale in good condition. These fruit would yellow quickly at the point of retail sale.

This result shows just how important maturity and storage temperature is for maintaining the quality of Pink Lady apples.

![Graph showing changes in background colour of Pink Lady apples](image)

Figure 17. Changes in the background colour of Pink Lady apples after removal from 3 months CA storage and 14 days at 20°C.

The results for the 6 month removal from storage tell a similar story. The changes in internal ethylene (Fig. 18) show that all the fruit had begun to ripen in storage as the ethylene levels straight after removal from storage were high (more than 10 ppm). This results support the industry feeling that Pink Lady apples should not be stored as long as November.

From a quality perspective the loss of flesh firmness was greatest for fruit from the later harvest (Fig. 19). This result highlights the importance of fruit maturity for ensuring maximum storage life and quality after storage. Fruit from harvest 1 maintained a higher level of firmness at both 0 and 3°C. However the firmest fruit were those stored at 0°C.

Fruit from the first harvest stored at 0°C also maintained a greener background colour than fruit from later harvests or at warmer temperatures (Fig. 20).
Figure 18. Changes in the internal ethylene levels of Pink Lady apples after removal from 6 months CA storage and 14 days at 20°C.

Fig 19. Changes in the flesh firmness of Pink Lady apples after removal from 6 months CA storage and 14 days at 20°C.

Fig 20. Changes in the background colour of Pink Lady apples after removal from 6 months CA storage and 14 days at 20°C.
3.6 Practical Outcomes for Pink Lady apples

These results highlight the importance of temperature management in cool stores and fruit maturity at harvest. These two factors have been shown to have a direct effect on fruit quality. The importance of temperature management and fruit maturity is often overlooked as a result of commercial management pressures, however this experiment has shown it is at the direct expense of fruit quality on out turn.

3.7 Induction of Flesh Browning of Pink Lady apples

Boron Deficiency

Pink Lady apples from an orchard in Tumut had internal browning on the tree. There was a concern that this may be an early version of the flesh browning seen after storage. However Granny Smith apples from the same areas in the orchard were showing clear symptoms of boron deficiency and so it was suspected that the Pink Lady apples also had a boron deficiency.

The symptoms of flesh browning observed are shown in the following pictures. The fruit on the top row are Granny Smith with severe symptoms and the other two rows are Pink Lady. The symptoms are different for Pink Lady. They don’t show the characteristic pitting seen in Granny Smith.

Photo 1. Examples of severe symptoms of internal browning in Granny Smith (top row) and Pink Lady apples.

Pink Lady apples (photo 2) show a band of flesh browning in parts of the cortex tissue rather than discrete pits. Apples with very severe symptoms did show some signs of pitting.
A mineral analysis was done on fruit from each sample. The fruit were freeze dried and then ground to a fine powder and then the minerals were extracted in 2N Nitric acid. The samples were centrifuged to obtain a clear extract and then analysed using ICP-AES and the analytical results expressed as mg/L (ppm).

Fruit were also testing using the Aweta Acoustic Firmness system. This unit is a non-destructive method for measuring fruit firmness. A commercial unit in Holland can run at a rate of 10 fruit per second on a packing line.

Table 1. Summary of the mineral analysis of the fruit samples.
The results for Ca, P and P are expressed as mg/100g fresh weight and B is expressed as (ppm).

<table>
<thead>
<tr>
<th>Variety</th>
<th>Symptoms</th>
<th>Ca</th>
<th>K</th>
<th>P</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granny Smith</td>
<td>None</td>
<td>6.65</td>
<td>95.38</td>
<td>10.36</td>
<td>3.57</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>6.19</td>
<td>99.18</td>
<td>10.76</td>
<td>2.40</td>
</tr>
<tr>
<td>Granny Smith</td>
<td>Severe</td>
<td>8.84</td>
<td>94.22</td>
<td>12.00</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>7.11</td>
<td>96.43</td>
<td>12.49</td>
<td>0.34</td>
</tr>
<tr>
<td>Pink Lady</td>
<td>None</td>
<td>4.92</td>
<td>83.26</td>
<td>7.92</td>
<td>1.24</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>5.69</td>
<td>81.96</td>
<td>7.59</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>4.76</td>
<td>74.45</td>
<td>7.65</td>
<td>1.05</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>5.01</td>
<td>75.24</td>
<td>7.88</td>
<td>1.13</td>
</tr>
<tr>
<td>Pink Lady</td>
<td>Severe</td>
<td>4.68</td>
<td>108.63</td>
<td>13.43</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>5.96</td>
<td>112.63</td>
<td>13.68</td>
<td>0.38</td>
</tr>
</tbody>
</table>

The results from the mineral analysis show that the fruit with no symptoms of flesh damage had higher levels of boron than those that showed symptoms (Table 1). In Granny Smith apples unaffected fruit has a mean level of 2.40ppm boron with the affected fruit having only 0.34ppm.
In Pink Lady apples the results were similar with unaffected fruit having levels of 1.23ppm fruit with moderate symptoms 1.13ppm and severely affected fruit had boron levels of 0.38ppm.

From these results it seems that the Pink Lady apples did show a boron deficiency and this is likely to be cause of the flesh browning seen in this instance.

Acoustic Firmness Results for Boron Deficiency

The acoustic firmness tester was used to determine if it was possible to detect the presence of flesh browning non-destructively. In Granny Smith apples the tester was not able to distinguish symptoms less that 60%.

Fig 21. Acoustic firmness results for Granny Smith apples with varying levels of boron deficiency symptoms.

Fig 22. Acoustic firmness results for Pink Lady apples with varying levels on flesh browning as a result of boron deficiency.

The acoustic tester was better able to determine the difference between damaged Pink Lady apples. The tester could determine fruit with up to 10% of the flesh damaged
with only a few errors. The fruit with symptoms of 10% or less were clustered between 35 and 50 units.

In Pink Lady apples the symptoms of boron deficiency affect a larger area of the flesh and the acoustic tester could measure the difference. It was less able to measure the symptoms in Granny Smith apples where the symptoms appear as discrete pits.

The Aweta acoustic firmness tester was also used for fruit from the CA storage induction trial (discussed in the next section). The symptoms induced were able to be very accurately differentiated by the Aweta acoustic firmness tester (Fig. 23).

![Graph](image)

Fig. 23. Correlation between the measurement of acoustic firmness and the percentage of flesh browning in the cortex of Pink Lady apples (sample size n = 189).

There was about a 5% error in detecting fruit with less than 10% of the cortex damaged. For higher damage levels the acoustic tester could very accurately differentiate the fruit.

The use of acoustic measurements as a non destructive test of flesh browning looks very promising. This method will be assessed more rigorously in the next trial (Horticulture Australia Project AP02009).
Induction of flesh browning in Pink Lady apples using CA storage.

A literature search turned up a paper written by Anderson (1967) which showed the flesh browning symptoms of Delicious apples stored in CA atmospheres with different combinations of oxygen and carbon dioxide (Photo 3). The results show that high carbon dioxide seems to induce flesh browning symptoms similar to that seem for Pink Lady apples.

Photo 3. Symptoms of flesh browning in Delicious apples after 6 months storage at 0°C and 7 days at 20°C (Anderson, 1967).

The results from our preliminary CA storage experiments also provide some insights into the possible causes of flesh browning in Pink Lady apples. However other researchers propose that the flesh browning disorder may be the result of more than one cause or could be more than one disorder depending on the location. The following series of photos is a summary of the results from our preliminary trials.

Photo 4. Symptoms of fruit stored in 20% CO$_2$ plus air at 20°C for 6 weeks.

Photo 5. Symptoms of fruit stored in 20% CO$_2$ plus air at 0°C for 6 weeks

Photo 6. Symptoms of fruit stored in 100% N$_2$ at 20°C for 6 weeks.

Photo 7. Symptoms of fruit stored in air at 0°C for 6 weeks.
Summary of Photographs

- High CO₂ at 20°C causes browning but as spots rather than the commercially seen band of browning.

- High CO₂ at 0°C causes severe browning more similar to commercial symptoms.

- “Commercial” symptoms of flesh browning can be induced by promoting anaerobic respiration. The internally produced CO₂ could be the cause of flesh browning.

- Induction of symptoms is relatively slow about 6 weeks at 20°C and so this is not a very rapid diagnostic test for susceptible fruit.

Future Work to be done by Sydney Postharvest Laboratory for the Flesh Browning of Pink Lady apples Project (Horticulture Australia Project AP02009)

- Preliminary results suggest that the disorder may be a function of limited oxygen and or high CO₂ in storage.

- Permeation of oxygen may be related to fruit density which is related to growing conditions.

- Aim to store fruit in a matrix of atmospheres containing different O₂ and CO₂ mixtures in an effort to induce flesh browning symptoms.

- Aim to correlate fruit density with the rate of induction of symptoms.

- Will carry out a mineral analysis to determine if B or Ca also play a role in inducing this disorder.
4. References


