Fumigation of fuji apples for export

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Scientific Horticulture Pty Ltd

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Fumigation of ‘Fuji’ apples for export

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Final Report AP02039 – Fumigation of Fuji apples for export

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Tasmania’s fruit fly free status has allowed the Tasmanian apple industry access to the lucrative Japanese market after the development of a fumigation protocol for the elimination of codling moth. This protocol was developed over a ten year period and access to the market was obtained in 1999. Shipments of fruit have been occurring since market access; however, the level of fumigation damage, expressed as a fumigation skin scald, internal browning and aggravation of ‘Fuji’ stain has presented problems. This project conducted experiments to determine the precise cause of the problems with the view of developing a protocol to eliminate fumigation damage in future shipments.

Acknowledgements
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Media Summary

Tasmania gained access to the Japanese market for fresh ‘Fuji’ apples in 1999. In order to avoid accidental introduction of codling moth into Japan it is a requirement that all ‘Fuji’ apples destined for Japan are fumigated with methyl bromide. Trial shipments of fruit were sent from Tasmania to Japan in 1999 and 2000 with positive market response. With increased confidence over 40 containers of fruit were shipped in 2001, however, in this season there were considerable fruit losses due to fumigation damage. Smaller volumes of fruit were fumigated and shipped in both 2002 and 2003 and in each season there were fruit losses due to fumigation damage. No shipments were planned for 2004 as the risk was considered too great especially in the buoyant local market conditions of that year.

Scientific Horticulture was requested and funded by Apple Exports Tasmania, who coordinate all shipments of fruit from Tasmania to Japan, to initiate investigations into fumigation damage in 2001. After a survey of known information from the 2001 season a research program was initiated in 2002 and continued for 2003, 2004 and 2005.

The research identified many factors contributing to the expression of fumigation damage. The major contributing factor was verified in 2004 as being attributable to the duration and temperature of storage between harvest and fumigation. To avoid fumigation damage it is essential to store fruit at 0°C for a minimum of 5 weeks prior to fumigation. Shorter durations and higher storage temperatures reduce the level of protection with there being no protection if fruit are stored at 5°C.

As a result of this finding an experimental container of fruit was successfully fumigated, shipped and marketed in Japan in late 2004. This provided industry with confidence that fumigation damage could be avoided and commercial shipments recommenced in 2005 with eight containers being successfully fumigated, shipped and marketed in Japan.

Technical Summary

Tasmania gained access to the Japanese market for fresh ‘Fuji’ apples in 1999. In order to avoid accidental introduction of codling moth it is a requirement that all ‘Fuji’ apples destined for Japan are fumigated with methyl bromide at 48gm⁻³ for 2 hours at a fruit temperature of 17°C. While close on 10 years of research into the treatment had been conducted in developing the fumigation protocol the focus of this research was on efficacy of the treatment and there was only minor studies on the treatment effects on fruit quality.

Trial shipments of fruit were sent from Tasmania to Japan in 1999 and 2000 with positive market responses. With increased confidence over 40 containers of fruit were shipped in 2001, however, in this season there was considerable fruit losses due to fumigation damage. Smaller volumes of fruit were shipped in both 2002 and 2003 and in each season there were fruit losses due to fumigation damage. Two major symptoms of fumigation damage were responsible for fruit rejections in Japan. Fumigation scald in 2001 and 2003, on the skin of
the fruit and internal browning, present in 2002. Fumigation was also found to aggravate the appearance of ‘Fuji’ stain. No commercial shipments were planned for 2004 as the risk was considered too great especially in the buoyant local market conditions of that year.

Scientific Horticulture was requested and funded by Apple Exports Tasmania, who coordinate all shipments of fruit from Tasmania to Japan, to initiate investigations into fumigation damage in 2001. After a survey of known information from the 2001 problems a research program was initiated in 2002 and continued for the 2003, 2004 and 2005 seasons. Research funding was also obtained from APIRD, Washington State University, Washington State Tree Fruit Research Commission and the United States Department of Agriculture. Some of these funds were matched by the Australian government through Horticulture Australia Limited.

As a direct result of this project one experimental container was successfully shipped in 2004 and this was increased to eight successful containers being commercially fumigated, shipped and marketed in 2005.

As part of this project many trials were conducted and many factors impacting on the appearance of fumigation damage were identified. It was found that earlier harvests of fruit were less prone to damage as were fruit that had been drenched in DPA (not allowed in Japan), antioxidants such as ascorbic acid or calcium chloride as Stopit®. The use of reflective cloth to improve fruit colour or colouring agents such as Ethrel® did not appear to be associated with an increase in the level of fumigation damage. It was also found that commercial fruit waxing and drying operations led to an increase in fumigation damage. In 2003 the application of wax resulted in an increase in fumigation scald from 5% to 25% and in 2005 the operation led to a 7 fold increase in ‘Fuji’ stain.

The significant finding pivotal to the successful fumigation and export of ‘Fuji’ apples was the impact of storage duration and temperature. In 2003 a pre-fumigation storage temperature of 12°C increased fumigation scald from 5% to 35% and in 2004 a storage temperature of 5°C did not reduce fumigation scald while 0°C almost eliminated it. It was concluded that fruit need to be stored at 0°C for a minimum of 5 weeks to reduce damage, even on mature fruit, to commercially acceptable levels. Storage at 5°C is not effective such that coldrooms used on a daily basis should be avoided and fruit should not be out of coldstorage for longer than necessary as this reduces the storage time at 0°C.

In 2005 investigations were initiated into CATTS (controlled atmosphere by temperature) disinfection of fruit as an alternative to methyl bromide. This project will continue in future seasons.
Introduction

‘Fuji’ apples have been exported from Tasmania to Japan since 1999, using a fumigation protocol against codling moth, of 48gm$^3$ methyl bromide (MeBr) for 2 hours at a fruit temperature of 17°C. This protocol was developed after many years of research by the Tasmanian Department of Primary Industry, Water and Environment. This research utilised research fumigation equipment throughout the year and had a focus on the efficacy of the treatment. No adverse effects on the fruit were noted although this aspect of the treatment was not studied in detail.

Despite successful exports in 1999 and 2000 fumigation damage developed in commercial consignments in the 2001, 2002 and 2003 seasons with fumigation scald in 2001 (Schimanski et al. 2001) and 2003 (Schimanski et al. 2003) and internal browning in 2002 (Brown et al. 2003). In addition it was found that MeBr fumigation caused an increase in the percentage of fruit expressing stain symptoms in 2002 and 2003 (Brown et al 2003 and Schimanski et al. 2003). These disorders have caused major financial loss to both importers and exporters (growers) and has led to lack of buyer confidence in the product. It is therefore necessary to control these problems if market confidence is to be regained and expanded.

The aim of research reported elsewhere was to study pre-harvest and post-harvest activities, and to identify actions with potential to have an impact after MeBr fumigation, on fumigation scald, internal browning and ‘Fuji’ stain. These studies have been funded by Tasmanian and American growers, exporters and government.

Fumigation scald was the first methyl bromide damage that caused commercial loss to exported Tasmanian fruit. It appeared in 2001 and was associated with the green side of the fruit. After a retrospective study (AP01031) it was thought that fumigation scald was due to condensation of water, in the tempering rooms, on the fruit skin and poor transport temperatures. Processes were introduced in 2002 to avoid water condensation on the fruit skin and this eliminated fumigation scald in 2002, but not 2003, suggesting that this was not a moisture condensation problem. The experimental trials conducted in 2003 identified
that fumigation scald was more pronounced on late harvest fruit, waxed fruit and that antioxidant pre fumigation drenches minimised the problem.

Internal browning damage was encountered in 2002 (AP01045) and it was hypothesised that the underlying cause was increased fruit respiration rate leading to carbon dioxide injury. The major factors associated with this disorder were late harvest fruit, waxing and the amount of time fruit remained out of the cold storage before fumigation. These factors were investigated further in 2003 (AP02039) and it was confirmed that the later harvested fruit were more susceptible to this disorder. Further, it was found that pre-fumigation storage temperatures of 5°C were associated with the lowest rates of all three disorders and waxing the fruit increased the incidence of internal browning and scald.

‘Fuji’ stain is a discolouration of the skin surface that occurs before fumigation; however, it is aggravated by the fumigation process. During the 2002 export season, despite a severe grading process, 25% of the fruit exported had stain symptoms on arrival in Japan. Research on this problem was initiated in the 2003 export season with funding from the Washington State growers, through the Washington State Tree Fruit Research Commission and Larry Schrader at Washington State University. This problem has been identified in Washington as having a major financial impact on the growers. Like the other disorders, stain was identified to be a physiological problem with increased incidence in more mature fruit and after the fruit has passed through the waxing and drying tunnel on the grader. It was also found that drenching in ascorbic acid or treatment with SmartFresh® reduced this problem.

The aim of the research conducted in the 2004 export season (AP03038) was to confirm the earlier findings of the influence of harvest maturity and storage temperature and duration on the appearance of methyl bromide damage. This research identified that storage temperature and duration after harvest was critical for fumigation damage. It identified that fruit had to be placed in 0°C for a minimum of 3, and preferably 5, weeks to eliminate the appearance of fumigation damage. Storage of fruit at 5°C was ineffective, indicating the need for good temperature management in the storage room. As in previous seasons, it was found that earlier harvested fruit were less susceptible to damage, however, it was also identified that this was due to the increased storage time at 0°C for these earlier harvested fruit. If the correct storage temperature and duration were applied then tree ripened fruit, with high levels of water core, could be fumigated without damage. Due to the financial losses encountered in previous seasons no containers of fruit were programmed to be exported to Japan in 2004. As a direct result of these research findings a late container of fruit was packed, fumigated and successfully exported to Japan with good returns to the grower reinvigorating and adding confidence back to the Japan export program.

As a result of this work eight containers of ‘Fuji’ apples were successfully exported to Japan in the 2005 season re-stimulating this as a viable export market for fruit.

2003 Experimental trials
Methods

This project was developed in consultation with Apple Exports Tasmania (AET), Tasmanian Department of Primary Industry, Water and Environment (DPIWE), Washington State University, Australian Quarantine and Inspection Service (AQIS) and Hobart Cold Storage Centre, Hobart Ports Corporation PTY. LTD. (HCSC).

Fumigation protocol

For all of the experiments in 2003, the following protocol was used in the fumigation procedures for ‘Fuji’ apples. Unless otherwise stated, experimental fruit were stored in export boxes at 0°C prior to fumigation, then removed from cold storage and left at ambient temperatures (approx. 10°C) for 3 days prior to tempering. The fruit were tempered at 17°C for 48 hours before fumigation and then fumigated with the commercial shipments. The fumigation chambers were operated at between 17 °C and 20 °C, with a target MeBr concentration of 48gm⁻³ for 2 hours, followed by four hours of ventilation. Commercial fumigations were initiated on May 10, approximately 10 days after harvest. After fumigation, all fruit were placed in a 0°C room and cooled to a core temperature between 0 and 4°C, using a forced draft cooling system, prior to shipment. Experimental fruit were placed into a refrigerated container for simulated transport (2.5°C for 3 weeks), then assessed for fumigation damage. The fruit were examined for external damage and cut open and assessed for internal damage. The number of fruit affected by fumigation scald, stain, internal browning (figures 1 to 3), dry rot, wet rot and mouldy core were recorded. The disorders were scored in a qualitative manner, fruit were assessed as having (i) no sign of the disorder (none), (ii) evidence of the disorder that would not be considered commercially significant (minor), or (iii) evidence of the disorder that would be considered commercially significant (severe). Unless otherwise stated, the results presented are based on the sum of the minor and severe categories.

Fruit maturity

Ten trees were selected from each of 4 orchard blocks. These were a stripe ‘Fuji’ plot and a blocked ‘Fuji’ plot from each of two orchards intending to export fruit to Japan. Harvests of fruit were made at weekly intervals from 4 weeks prior to commercial harvest. At each harvest approximately 90 fruit (1 box) from each of 2 trees was randomly picked and a different pair of trees was harvested each week. Fruit maturity assessments, firmness, TSS, honeycore, colour and starch, were conducted on 20 fruit for each harvest and each grower. The remaining fruit were fumigated and assessed as per the fumigation protocol stated above. Data for the means at each harvest was analysed using a split plot ANOVA.

Duration out of cold storage prior to fumigation

‘Fuji’ apples from one grower were commercially harvested and hand graded, the fruit were loose packed (approx. 80 fruit/box) and stored at 0°C for a minimum of 2 weeks. Eight boxes of fruit were placed in ambient conditions (12°C) at each of the following removal times; 9, 6, 3, and 0 days prior to transport to the fumigation centre. The fruit were tempered and fumigated as per the fumigation protocol outlined above. After fumigation, 4
boxes from each removal date were placed in a 0°C coolroom, while the other 4 boxes were kept at 12°C for 24 hours before placement in the coolroom.

**Pre-fumigation drenches and 1-MCP fumigation**

‘Fuji’ apples from three growers were commercially picked, hand graded and placed into plastic bins (c.f. 80 fruit per/bin). There were three replicates (bins) of seven treatments applied to the fruit, (i) untreated control, (ii) fumigation in a purpose built, chamber with 1-MCP (Smartfresh™) for 24 hours at 15°C, treatments iii-vii were all drenched for one minute using custom built drenching equipment to simulate commercial practice. (iii) 1% Stopit®, (iv) 2% Stopit®, (v) 1% ascorbic acid (vi) 2% ascorbic acid (vii) 0.6% diphenylamine (DPA). The apples were then loose packed into export boxes and placed into cold storage (5°C). The fruit were fumigated and assessed as per the fumigation protocol stated above.

A sub-sample of 4 fruit from each of the 3 replicates per grower for each of the treatments above, both before and after fumigation were weighed and placed in an airtight plastic container with rapid airflow to ensure no build up of CO₂ and O₂. On a total of 11 occasions, at 2-3 day intervals during the simulated transport, the airflow was stopped for 4-6 hours to allow ethylene and CO₂ to increase to accurately measurable quantities using a PacIII Drager ethylene analyser and a Besserling CO₂ analyser. Preliminary trials were conducted to ensure that both ethylene and CO₂ increased linearly over this time period. After 3 weeks the fruit were assessed for TSS, firmness and fumigation damage as described above. Data was analysed using ANOVA.

**Grading line**

‘Fuji’ apples were collected from two commercial grading lines. The fruit were collected from the following seven locations (i) field bins before grading process begins, (ii) after the first dump tank, (iii) after the first sorting table and hot water treatment, (iv) after the first drying process, (v) after the waxing jets, (vi) after the heat tunnel, (vii) after final grading, at the point were fruit were packaged where reject fruit were sampled. Three replicates (boxes of approx. 80 fruit) per grader location were collected. Fruit were loose packed into export boxes and stored at 5°C before fumigation. The fruit were fumigated and assessed as described above. Data were analysed using a split plot ANOVA.

**Pre-fumigation storage temperatures**

‘Fuji’ apples from three growers were commercially picked, hand graded, and loose packed (approx. 100 fruit/box) into export boxes. Three replicates (boxes) were placed into each of three storage temperatures (0, 5 or 12°C) for 14 days before fumigation. The fruit were fumigated as per the fumigation protocol stated above and placed into simulated transport. A sample of 4 fruit from each of the 3 replicates per grower (12 fruit, weights were recorded) for each of the treatments above, both before and after fumigation, was placed in an airtight plastic container with rapid airflow to ensure no build up of CO₂ and O₂. On a total of 8 occasions, at 2-3 day intervals during the simulated transport, the airflow was
stopped to measure ethylene and carbon dioxide production rate as previously described. After 3 weeks the fruit were assessed for firmness, TSS and fumigation damage as described above.

Results and discussion

Fruit maturity
In this trial fruit were harvested at weekly intervals and stored prior to fumigation on one date. For the sake of this study, due to the survey results from the 2001 season, it was assumed that treatment effects were due to maturity at harvest, however, in a later study it was identified that the duration that the fruit are in a coldroom prior to fumigation has a significant impact on the appearance of fumigation damage. In 2003 fruit fumigation was initiated approximately 10 days after harvest.

The analyses for fumigation damage indicated significant interactions between grower and harvest date, therefore, grower lines were examined separately. All of the grower lines, except Grower 2 block ‘Fuji’, had unacceptable levels of fumigation scald at commercial harvest (Fig. 8a). Of the three lines in which the incidence of scald increased prior to harvest, minimal fumigation scald was encountered when the maturity index was greater than 100, 2-3 weeks before commercial harvest or when fumigation was harvested approximately 4 weeks prior to fumigation (Fig. 8a). Thus, if growers were to pick two weeks prior to current commercial practice they would significantly reduce the incidence of fumigation scald for fumigations in early May.

Fruit colour is a concern in ‘Fuji’ apples destined for the export markets; therefore the fruit is often left on the tree past the optimum harvest date to improve red colour development. Trials on ‘Fuji’ apples in 2002 (Brown et al. 2003a) and on ‘Pink Lady’ apples in 2001 and 2002 (Brown et al. 2003b) have indicated that reflective cloth will improve red colour without advancing fruit maturity. The trials on the ‘Pink Lady’ apples have also shown that selected growth regulators are also effective at improving colour without advancing maturity (Brown et al. 2003b).

There were no commercially significant levels of internal browning in 2003; however, the incidence of this disorder did appear to increase when the maturity index was below 100 at harvest (1 week before commercial harvest, 3 weeks from harvest till fumigation Fig. 8b) which is consistent with results from the 2002 season. At commercial harvest, three of the grower lines showed commercially significant levels of stain on the fruit (Fig. 8c). The pattern of increase in this disorder was inconsistent; however, it did increase with maturity, particularly after a maturity index of 200 (Fig. 8c).
Generally, the more mature the fruit, or the shorter the period from harvest till fumigation, the more susceptible they are to fumigation damage. Hence, although red colour development is essential for the fruit to reach specifications for the Japanese market, this should not be achieved by leaving the fruit on the tree past the optimum harvest date for a fumigation in early May. Other techniques to improve colour, such as reflective cloth and growth regulators should be explored.

**Duration out of cold storage before fumigation**

This trial was only conducted with one grower, and overall there were very low levels of both scald and internal browning in these experimental fruit such that results need to be treated with care. However, the data suggested that the longer fruit were left out of cold storage before fumigation the greater the incidence of scald (Table 4). Fumigation scald was greater in fruit that was left out of storage 9 days before transport to the fumigation centre than fruit that was transported directly after removal from cold storage (Table 4). However, this won’t be achieved in a commercial situation where several days are needed to grade and pack. Interestingly, the incidence of commercially significant fumigation scald (severe) was not affected by time out of cold storage (Table 4). There was no commercially significant result for internal browning, as all levels were below the 2% threshold of tolerance for the disorder in this line of fruit (Table 4).

<table>
<thead>
<tr>
<th>Days in advance of fumigation</th>
<th>Total scald (%)</th>
<th>Severe scald (%)</th>
<th>Total internal browning (%)</th>
<th>Severe internal browning (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.01 a</td>
<td>0.33 a</td>
<td>0.00 a</td>
<td>0.00 a</td>
</tr>
<tr>
<td>9</td>
<td>3.42 b</td>
<td>0.66 b</td>
<td>0.00 b</td>
<td>0.00 b</td>
</tr>
</tbody>
</table>

Table 4  Fumigation damage due to time out of cold storage before fumigation

**Figure 8a.** The effect of fruit maturity on fumigation scald

**Figure 8b.** The effect of fruit maturity on internal browning

**Figure 8c.** The effect of fruit maturity on stain
Leaving the fruit at ambient temperature between fumigation and cold storage did not appear to affect the incidence of fumigation scald; however it was associated with an increase in the incidence of internal browning (Table 5). The results of this trial for both these disorders should be viewed with caution since the levels of the disorders were extremely low. The results for the time out of cold storage before fumigation in this season conflict with the results of experimental trials in 2002 (Brown et al. 2003a).

**Pre-fumigation drenches and 1-MCP fumigation**

The analysis of fumigation scald indicated significant interactions between grower and pre-fumigation treatment; therefore, all the grower lines were examined separately. Grower 1 and 3 had very low levels of fumigation scald, and except for the levels of scald in the MCP treatment for Grower 1, these levels were not different from the untreated control (Fig. 9a). Grower 2, however, recorded very high levels of fumigation scald, and all of the drenches were associated with a reduction in the occurrence of this disorder, when compared to the current practice of no treatment, MCP fumigation, however, significantly increased the occurrence of fumigation scald such that this material should not be used prior to fumigation (Fig. 9a). DPA resulted in the lowest levels of scald, however Stopit® and 1% ascorbic acid were also very effective (Fig. 9a).

### Table 5  Fumigation damage due to time out of cold storage after fumigation

<table>
<thead>
<tr>
<th>Days</th>
<th>Total fumigation scald (%)</th>
<th>Severe fumigation scald (%)</th>
<th>Total internal browning (%)</th>
<th>Severe internal browning (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3.38 a</td>
<td>0.65 a</td>
<td>0.25 a</td>
<td>0.00 a</td>
</tr>
<tr>
<td>1</td>
<td>4.44 a</td>
<td>0.33 a</td>
<td>1.23 b</td>
<td>0.08 a</td>
</tr>
</tbody>
</table>

Means in a column with a different letter considered different $p = 0.05$
The analysis of internal browning also indicated significant interactions between grower and pre-fumigation treatment; therefore, all the grower lines were examined separately. Grower 3 showed no significant difference between any of the treatments for internal browning, and the levels were commercially insignificant (Fig. 9b). Overall, growers 1 and 2 showed very similar patterns in the affects of treatments on the levels of internal browning, except grower 1 had much lower levels of the disorder (Fig. 9b). For both Grower 1 and Grower 2, DPA, 2% Stopit® and 2% ascorbic acid significantly reduced internal browning. DPA provided the greatest control of internal browning (Fig. 9b), however, since DPA is not permitted for use on fruit destined for Japan, both ascorbic acid and Stopit® warrant further investigation as possible protectants against MeBr fumigation damage, particularly the higher concentrations of both these materials. The use of Stopit® as a pre-harvest spray should also be investigated.

Fuji stain was not as severe in the 2003 season with less than 10% of the fruit displaying symptoms. There was no significant grower and treatment interaction in the analysis of stain, therefore the data was averaged across all growers. MCP and 2% ascorbic acid were the most effective treatments against stain, while none of the other treatments reduced this disorder compared to the untreated control (Fig. 9c). Stain is not as obvious as the other two disorders and as yet there are no specifications for its level of acceptance in Japan. Therefore, it is difficult to determine the commercial significance of the levels of stain observed in this experiment, however, given that up to 40% of fruit were affected in 2002 it is important to develop methods of reducing this disorder to guarantee reliable supplies of fruit with excellent skin finish.
Figure 9a. The effect of pre-fumigation drenches on fumigation scald *

*Legend for Figures 5, 6 and 7
UTC = untreated control  2% SI = 2% Stopit®
DPA = Diphenylamine  1% AA = 1% ascorbic acid
1% SI = 1% Stopit®  2% AA = 2% ascorbic acid
MCP = 1-MCP (Smartfresh™)

Figure 9b. The effect of pre-fumigation drenches on internal browning *

Figure 9c. The effect of pre-fumigation drenches on stain *

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The data for fruit ethylene production and respiration rate (table 6) clearly demonstrated that fumigation with methyl bromide substantially reduced the rate of ethylene production and this was associated with a reduction in the respiration rate of the fruit. This indicates that the hypothesis developed from the 2002 trials, that methyl bromide fumigation leads to an increased rate of respiration, and thus to CO₂ damage of the fruit, apparent as internal browning of fumigated fruit is incorrect. Hence the data suggests that fumigation induced internal browning is not due to a stimulation of the fruit respiration rate and the opposite may be true, that internal browning is associated with reduced rates of respiration in the fruit. It is unfortunate in this trial that internal browning was not encountered in the 2003 season to clarify this situation. Fumigation of the fruit had no effect on fruit firmness or sugar content.

For the drenches it was found that all reduced both the rate of ethylene production and the respiration rate of the fruit. Smartfresh® (1-MCP) was the most efficacious material and resulted in ethylene production rates about a third that of the control fruit and a fruit respiration rate nearly half that of the untreated fruit. DPA was also effective and reduced ethylene production to just over one half the control fruit and the respiration rate to 90 percent of the untreated. The ascorbic acid and Stopit® materials provided a similar reduction in ethylene rate and a small, and, in the case of Stopit®, statistically significant reduction in the rate of fruit respiration. While all materials reduced the rate of fruit softening and increased fruit sugar content, only MCP resulted in firmer fruit at the time of marketing. There was no statistical effect of the materials on fruit sugar content.

<table>
<thead>
<tr>
<th></th>
<th>Ethylene µg/kg/hr</th>
<th>Respiration mgCO₂/kg/hr</th>
<th>Firmness N</th>
<th>TSS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Fumigated</td>
<td>4.67 a</td>
<td>2.60 a</td>
<td>78.1 a</td>
<td>13.0 a</td>
</tr>
<tr>
<td>Fumigated</td>
<td>2.04 b</td>
<td>2.39 b</td>
<td>80.0 a</td>
<td>12.6 a</td>
</tr>
<tr>
<td>Untreated</td>
<td>4.46 d</td>
<td>2.73 d</td>
<td>76.6 a</td>
<td>12.6 a</td>
</tr>
<tr>
<td>DPA</td>
<td>2.97 b</td>
<td>2.47 b</td>
<td>80.1 a</td>
<td>12.8 a</td>
</tr>
<tr>
<td>1% Stopit</td>
<td>3.69 c</td>
<td>2.59 bc</td>
<td>77.5 a</td>
<td>12.7 a</td>
</tr>
<tr>
<td>2% Stopit</td>
<td>3.78 c</td>
<td>2.60 c</td>
<td>77.9 a</td>
<td>12.9 a</td>
</tr>
<tr>
<td>1% Ascorbic acid</td>
<td>3.86 c</td>
<td>2.68 cd</td>
<td>77.4 a</td>
<td>12.9 a</td>
</tr>
<tr>
<td>2% Ascorbic acid</td>
<td>3.33 bc</td>
<td>2.67 cd</td>
<td>77.2 a</td>
<td>13.0 a</td>
</tr>
<tr>
<td>Smartfresh®</td>
<td>1.39 a</td>
<td>1.74 a</td>
<td>86.6 b</td>
<td>12.7 a</td>
</tr>
</tbody>
</table>

Means in a column with a different letter considered different \( p = 0.05 \)

One interesting relationship was observed in the data for fruit respiration rate and the final fruit firmness at marketing (figure 10). Here it was found that the higher rates of fruit respiration were associated with softer fruit at marketing indicating that low fruit respiration rates are necessary for maintaining fruit firmness. As DPA and Stopit® led to reduced rates of fruit respiration then, while in these trials no difference in fruit firmness was noticed, after prolonged storage and marketing these treatments may lead to observable improvements in fruit firmness.
Interestingly, for the identified disorders associated with the fumigation of ‘Fuji’ apples, ascorbic acid was the only treatment that was effective in all cases and it also led to a small reduction in ethylene production. This material is an anti-oxidant that is already a food-grade material; therefore it should not be difficult to obtain registration for use as a post-harvest drench. Further research is required on this group of materials, to determine appropriate concentrations and application techniques. Alternatively, as ascorbic acid is a natural component of apples methods of increasing natural levels should be developed. The alternative compound tested, Stopit®, also reduced all three disorders and reduced both ethylene production and fruit respiration rates and is possible that excellent control may be achieved with this material with more efficacious application. As this material is currently registered for use on apples its adoption could be rapid. Of the remaining materials DPA is not allowed on apples destined for many markets including Japan and MCP, while having excellent results for the control of stain, reduced ethylene production and respiration rate, provided no protection against fumigation damage. As a result this material will prove very useful against stain and prolonging fruit storage life for fruit that does not need to be fumigated.

**Grading line**

There was a grower by treatment interaction in this trial for all of the disorders; however, for ease of explanation the average of the two growers was presented, as the differences between the graders was not large. The incidence of fumigation scald at the end of grading was 3 times higher than at the beginning (Fig. 11a). For both growers, this increase occurred with wax application, however, in one grower the levels of fumigation scald reduced after wax application possibly due to the subsequent brushes spreading the wax and/or removing the wax from the fruit, while for the other grower the levels of scald actually continued to increase after wax application. This may indicate differences in
grading equipment and sorting procedures after waxing. Importantly, fumigation scald increased significantly after waxing, thus it may be necessary to explore wax alternatives. There are a number of food grade alternatives already on the market with potential and research has been initiated studying one of these.

The incidence of internal browning nearly doubled by the end of grading (Fig. 11b). While the point where this increase occurred is not as well defined as for scald, it reached a maximum at the waxing process, and becomes significantly higher than the bins (untreated control) at the waxing application.

However, it should be noted that for one of the growers the increase in the incidence of internal browning actually occurred at the first drier. Thus, it is unclear whether it is the heat or the waxing process that aggravates this disorder on the grading line, and it could occur at different points depending on the grower. Of interest is the level of internal browning encountered, which, at 20% was much higher than 4 of the lines that were exported to Japan.

Stain only occurred at very low levels, with a slight, but insignificant increase at the waxing application and final drying tunnel (Fig. 11c). This suggests that the heat involved in the final drying tunnel was responsible for the observed increase in stain, although, due to the low levels encountered and large observed variation this finding needs to be verified.

Pre-fumigation storage temperatures

Of the three growers in this trial only the fruit from one grower displayed any treatment affects. Therefore, only the results from this grower are presented. Pre-fumigation fruit storage at ambient temperature (12°C) increased scald 3 fold compared to storage at either 0°C or 5°C (Fig. 12a). Interestingly, the lowest internal browning levels were recorded in the fruit stored at 5°C, while there was over a 100% increase in internal browning between 5°C and 12°C, and the incidence of the disorder at 0°C is intermediate between these two temperatures (Fig. 12b) as has been observed in the field. For this grower, stain appeared to decrease with increasing storage temperature (Fig. 12c), however, it should be noted that for stain, the growers gave inconsistent results. The results for scald and internal browning
indicate that fruit should be stored at 5°C prior to fumigation to minimise both fumigation scald and internal browning. Further studies are needed to verify the precise optimal storage temperature as the range from 5 to 12°C is large.

For the rates of ethylene production (table 7), as for the drenching trial, the fumigation of the fruit with methyl bromide resulted in a reduced rate of ethylene production. In this smaller trial, however, the fumigation treatment was not observed to influence the rate of respiration. The finding that methyl bromide had no affect on the rate of fruit softening or fruit sugar content confirms the previously report study.

One interesting result is that pre fumigation storage temperature had an influence on the level of ethylene production with the fruit stored at ambient temperatures having the highest rate of ethylene production. These results suggest that coldstorage of fruit at 5°C reduces the rate of ethylene production either through some preconditioning of the fruit or by reducing the level of maturity at the time of measurement. While no differences in the level of fruit respiration were noted it is interesting to observe that the measured rates reflect the rate ethylene production. The fruit stored at ambient had the highest rates followed by fruit stored at 0°C with fruit being stored at 5°C having the lowest levels of all three parameters.

In this trial the treatment with the highest rate of ethylene production was associated with the treatment with the highest rates of fumigation scald. This is the opposite of the drenching trial suggesting that there is no link between the level of ethylene production and fumigation scald.
The maturity trial indicated that internal browning increased markedly with either maturity at harvest or with reduced duration between harvest and fumigation. Fumigation scald also increased with maturity although the relationship was not as strong and was variable between grower lines. There was no statistically significant relationship between stain and maturity, however, stain was observed to increase with later harvest dates. In all cases the level of these problems was minimised if fruit were harvested before a maturity index of 150 or greater than 4 weeks prior to fumigation.

There was a trend toward an increasing incidence of fumigation scald the longer the fruit were removed from the cold room before fumigation. However, it should be noted that the levels of fumigation scald observed in the experimental fruit were very low (4%) and that not allowing the fruit to raise to ambient temperature before placement into tempering may result in high humidity and condensation of moisture on the fruit skin that may lead to fumigation problems. It is not considered that there was any commercially significant increase in internal browning (1.6%) with days out of cold storage before fumigation in this trial.

A pre-fumigation storage temperature of 12°C increased fumigation scald from 5% to 35%. The effect of temperature was less marked on the incidence of internal browning, however this higher temperature actually resulted in a decrease in the incidence of stain. It was also found that fruit stored at 12°C had the highest rate of ethylene production. From these preliminary trials a pre-fumigation storage temperature of 5°C appears to result in the least damage overall and superior fruit quality when all three disorders are considered although further research is needed to clarify this and identify the optimal storage temperature.

Pre-fumigation drenches may be useful in minimising the incidence of fumigation related disorders. The use of Stopit®, which is already registered, and to a lesser extent ascorbic acid was particularly effective in reducing the incidence of scald. Ascorbic acid was also

| Table 7: Fumigation and storage temperature effects on fruit respiration and quality |
|---------------------------------|------------------|------------------|------|-------|
|                                | Ethylene µg/kg/hr | Respiration mgCO₂/kg/hr | Firmness N | TSS % |
| Not Fumigated                  | 4.60 a            | 2.65 a            | 76.1 a | 13.5 a |
| Fumigated                      | 2.67 b            | 2.65 a            | 76.8 a | 13.2 b |
| 0                              | 3.39 a            | 2.62 a            | 77.9 a | 13.3 a |
| 5                              | 3.28 a            | 2.54 a            | 77.9 a | 13.2 a |
| 12                             | 4.23 b            | 2.79 a            | 73.5 a | 13.6 a |

Means in a column with a different letter considered different $p = 0.05$

Conclusions 2003

The maturity trial indicated that internal browning increased markedly with either maturity at harvest or with reduced duration between harvest and fumigation. Fumigation scald also increased with maturity although the relationship was not as strong and was variable between grower lines. There was no statistically significant relationship between stain and maturity, however, stain was observed to increase with later harvest dates. In all cases the level of these problems was minimised if fruit were harvested before a maturity index of 150 or greater than 4 weeks prior to fumigation.
effective against internal browning and stain, while, 1-MCP (Smartfresh®) exacerbated both scald and internal browning although it was effective against stain. DPA provided the most control against both scald and internal browning, although this material is not permitted by the Japanese authorities. From these results 1-MCP will provide excellent control of stain in fruit that is not going to be fumigated while ascorbic acid, and to a lesser extent, Stopit®, will provide useful reductions in all three disorders for fruit that is to be fumigated. The effect of field applications of Stopit® on these disorders is not known but this delivery system may prove to be extremely effective.

The grading line had a significant effect on the incidence of scald. The application of wax resulted in an increase in fumigation scald from 5%-25%. However, it must be remembered that in 2002, commercially there was no occurrence of fumigation scald, yet all the fruit fumigated were waxed, therefore there must be other factors predisposing fruit to the appearance of scald. The effect of the grading line on internal browning was less marked, although the level of internal browning had doubled by the time the fruit entered the drying tunnel after waxing. There was no consistent relationship between any stage of the grading line and the occurrence of stain although the drying tunnel after waxing appears to be a cause of concern.
2004 Experimental trials

Methods

Fumigation protocol
For all of the experiments outlined below, the following protocol was used in the fumigation procedures. Unless otherwise stated, experimental fruit were stored in boxes at 0°C prior to fumigation, then removed from cold storage and left at ambient temperatures (approx. 10°C) for 3 days prior to tempering. The fruit were tempered at 17°C for 48 hours and then fumigated with the same equipment as used for the commercial shipments. The fumigation chambers were operated at between 17°C and 20°C, with a target MeBr concentration of 48gm⁻³ for 2 hours, followed by four hours of ventilation. After fumigation, all fruit were forced draft cooled to a target temperature of 0°C. Experimental fruit were placed into a refrigerated container for simulated transport (5°C for 3 weeks), then assessed for fumigation damage. The fruit were examined for external damage and cut open and assessed for internal damage. The number of fruit affected by scald, stain, internal browning and core rots were recorded. The disorders were scored in a qualitative manner, fruit were assessed as having (i) no sign of the disorder (none), (ii) evidence of the disorder that would not be considered commercially significant (minor), or (iii) evidence of the disorder that would be considered commercially significant (severe). Unless otherwise stated, the results presented are based on the sum of the minor and severe categories.

Storage temperature and duration from harvest prior to fumigation
'Fuji' apples from three growers were commercially harvested and hand graded, the fruit were loose packed (approx. 80 fruit/box) on 27 April 2004 and stored at 0°C or 5°C for 1, 3 or 7 weeks. After removal from cold storage the fruit were maintained at 17°C for 5 to 7 days before fumigation. After fumigation (May 6, May 21, June 29) the fruit were stored and assessed as per the fumigation described above. Fruit from grower 3 had been treated with Smartfresh® within 2 days of harvest. Data was analysed by factorial Analysis of Variance.

Fruit maturity
Ten trees were selected from each of 4 orchard blocks. Harvests of fruit were made at weekly intervals from 4 weeks prior to commercial harvest till one week after commercial harvest (24 March 2004 till 21 April 2004). At each harvest approximately 320 fruit (4 boxes representing 4 replicates) from different sets of trees was randomly picked and a different set of trees was harvested each week. Firmness, TSS, honeycore, colour and starch, were conducted on 20 fruit for each harvest and each grower. From these measurements the fruit maturity index was calculated. The remaining fruit were fumigated
Pre-fumigation drenches

‘Fuji’ apples from one grower with a history of fumigation damage were commercially picked, hand graded and placed into plastic bins (c.f. 80 fruit per/bin) on April 27 2004. There were four replicates (bins) of seven treatments applied to the fruit as follows;

1) untreated control
2) 2% Stopit®
3) 1% ascorbic acid
4) 2% ascorbic acid
5) A new potential antioxidant for use on fruit SH T2, 1%
6) 1% Ascorbyl Palmamate
7) mixture of 5 and 6

After treatment the apples were then loose packed into export boxes, fumigated (May 6) and assessed as per the fumigation protocol stated above. Data was analysed using ANOVA.

Pre harvest colouration treatments

For the marketing of ‘Fuji’ apples it is imperative that high levels of fruit colour are achieved. One way of improving fruit colour is by the use of chemicals including growth regulators. Growth regulators act by modifying a fruits physiology and thereby have the potential to affect the appearance of physiological disorders such as those encountered with fumigation damage. As a result, a trial was conducted whereby trees were sprayed with various chemicals and their impact on fruit colour, fumigation damage studied. The treatments were as follows

1) Untreated control
2) BA (Bapsol®) at 9L formulated product/Ha (6-Benzylamino purine)
3) Ethrel® at 300ml formulated product/Ha
4) Abscisic Acid at 300g active/Ha
5) Sucrose at 10kg/Ha
6) Potassium Thiosulphate at 7kg/Ha
7) Quinmerac® at 200g formulated product/Ha

Sprays were applied with a hand lance in 750L water/Ha on 11 March 2004, 19 March 2004, 24 March 2004 and 31 March. 20 fruit were harvested from shaded areas around the base of the trees and 20 fruit from sunny positions on April 4 2004. The fruit were stored at 0°C until fumigated on May21 2004. In addition to fumigation damage fruit were assessed for flecking (a form of russet on a visual 0 to 10 scale where 0 represents no flecking), red colour area (visual assessment – number of fruit with a colour area greater than 60%) fruit weight, sugar content (TSS) and firmness. Data was analysed using a split plot ANOVA.
**Results and discussion**

*Storage temperature and duration from harvest prior to fumigation*

Growers 1 and 2 harvested their fruit within a few days of each other (Table 8) and the fruit had similar firmness, starch, sugar levels and hence fruit maturity (maturity index). Fruit from Grower 3 were harvested 10 days earlier than the other growers resulting in fruit that had more starch and lower sugars and therefore were less mature at harvest (higher harvest index). In addition, fruit from Grower 3 were treated with SmartFresh® within a few days of harvest.

<table>
<thead>
<tr>
<th>Grower</th>
<th>Harvest Date</th>
<th>Firmness (kg)</th>
<th>Sugars (% TSS)</th>
<th>Starch (% black)</th>
<th>Maturity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24 April</td>
<td>8.1</td>
<td>14.2</td>
<td>10.6</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>21 April</td>
<td>8.0</td>
<td>13.2</td>
<td>9.5</td>
<td>57</td>
</tr>
<tr>
<td>3</td>
<td>14 April</td>
<td>8.0</td>
<td>12.0</td>
<td>20</td>
<td>130</td>
</tr>
</tbody>
</table>

Honey core is important for marketing of apples in Japan and it was found that grower 1 produced fruit with high levels of this feature (Table 9). Grower 2 had intermediate levels of honey core, but these were substantially higher than Grower 3 who had the least mature fruit at harvest and no honey core in the fruit. Significantly, for core rots it was found that Grower 1 had levels above market specification (usually 2% and sometimes as low as 1%) and these fruit risked market rejection due to this disease. Core rots were within market specifications for Growers 2 and 3.

For fumigation damage, it was found that fruit from growers 1 and 2 encountered problems while those from Grower 3 did not express any fumigation damage (Table 9). During the 2003 research it was concluded that the level of fumigation damage was minimised if fruit were harvested with a maturity index above 150. Although all the fruits this season had a lower maturity index than 150 of the three growers studied in 2004 Grower 3 had the least mature fruit at harvest, supporting the findings of 2003. It was also found in the 2003 season that SmartFresh® treated fruit were more susceptible to fumigation scald. As the fruit from Grower 3 were Smartfresh® treated in 2004 and damage was not encountered indicates that either the influence of maturity or the duration between harvest and fumigation (6 days in 2003, 3 weeks in 2004), is more important than Smartfresh® treatment. These results indicate that fruit that is picked at the correct maturity, or stored prior to fumigation, can be safely Smartfresh® treated and fumigated.

As fruit from Grower 3 did not express symptoms of fumigation damage the data was removed from further statistical analysis to improve trial sensitivity.
Table 9. The effect of grower on honey core, core rots and fumigation damage

<table>
<thead>
<tr>
<th>Grower</th>
<th>Honey core (%)</th>
<th>Core rots (%)</th>
<th>Fumigation scald (%)</th>
<th>Stain (%)</th>
<th>Internal browning (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60 a</td>
<td>3.0 a</td>
<td>4.2 a</td>
<td>0.3 b</td>
<td>8.8 a</td>
</tr>
<tr>
<td>2</td>
<td>19 b</td>
<td>0.9 b</td>
<td>1.2 b</td>
<td>2.2 a</td>
<td>3.5 b</td>
</tr>
<tr>
<td>3</td>
<td>0 c</td>
<td>0.7 b</td>
<td>0.2 c</td>
<td>0.1 c</td>
<td>0.0 c</td>
</tr>
</tbody>
</table>

Means in a column with a different letter considered different $p = 0.05$

Storage temperature and duration from harvest prior to fumigation

As reported above honey core in apples destined for Japan is a desirable trait. In these trials it was found that honey core remain high for fruit stored for either 1 or 3 weeks prior to fumigation (figure 13) although levels dropped dramatically by 7 weeks of storage. It is probable that levels are adequately high with up to 5 weeks of storage prior to fumigation and shipment to Japan.

![Figure 13. The effect of storage period prior to fumigation on average honey core for Gowers 1 and 2](image)

Fumigation scald was found to adversely affect commercial shipments to Japan in 2001 and again in 2003. No shipments were planned in 2004 due to concerns about fumigation damage. Research conducted in 2004, however, identified that this fumigation damage was related to storage temperature and duration (Figure 14). If fruit were stored at 0°C unacceptable levels of fumigation scald were encountered after one week of storage, however, scald was reduced from 5 to less than 0.5% of the fruit after 3 weeks of storage and was not detectable after 7 weeks of storage. However, storage temperature was also critical, if the fruit were stored at 5°C then unacceptable levels of fumigation scald were encountered at all storage durations.
It was found that the storage temperature had no effect on the appearance of internal browning after fumigation (data not presented). The storage duration after harvest, however, was associated with a dramatic reduction in the appearance of internal browning (Figure 15). After 1 week of storage prior to grading, tempering and fumigation, levels of internal browning after fumigation were unacceptable. After 3 weeks of storage there was a dramatic reduction in the appearance of fumigation scald to just above 2% of the fruit, which is still above market specifications for internal disorders. After 7 weeks of storage, however, internal browning was below 0.5%, well within market specifications.
Fruit maturity

During the 2002 and 2003 trials it was found that fumigation damage increased significantly with each week delay in fruit harvest. During the 2004 season this research was repeated on 4 growers properties and similar results were obtained (Figure 16). Harvests on or before April 7 were associated with very low levels of fumigation damage. Harvests after this date were associated with a dramatic increase in internal browning to unacceptable levels, while harvests after April 14 were also associated with increases in both fumigation scald and stain to unacceptable levels.

However, this pattern of damage was different to both the 2003 and 2002 season where it was found that external damage appeared before internal damage. It has also been observed that there is seasonal affect on the relative importance of the three types of fumigation damage. In 2002 fumigation scald was not encountered and at the last harvest, stain levels (6% of fruit) were half the levels of internal browning (12%). During the 2003 season it was found that both stain and fumigation scald affected about 20% of fruit compared with 1% of the fruit affected with internal browning and finally in 2004 both stain and fumigation scald affected about 5% of fruit compared with 20% of the fruit for internal browning.

![Figure 16. The effect of harvest date on the average fumigation induced disorders for 4 growers](image-url)
Fruit maturity and storage duration prior to fumigation

It was reported above, that the duration at 0°C prior to fumigation had a large impact on the appearance of fumigation damage. For the fruit maturity studies, the early harvested fruit were stored at 0°C till all harvests were completed prior to fumigation. Hence, fruit from the first harvest date were stored for a longer period of time than fruit from the final harvest date prior to fumigation. In order to study this in the 2004 maturity trial, data for the same two orchards used for the storage duration trial were plotted, against storage duration (Figure 17). This revealed a close association between the two data sets, indicating that the duration of storage at 0°C is responsible for the reduction in fumigation damage and not the maturity at harvest. Of interest, is that the trial investigating the effect of storage duration on fumigation damage used tree ripe fruit (Growers 1 and 2) and damage was minimal after 3 weeks of storage at 0°C during this season. As a result of these trial results, after the 3 week fumigation a single container of fruit was organised for marketing in Japan with fumigation occurring after 7 weeks of storage. This container of fruit was successfully marketed with no fumigation damage being observed in Japan.

Figure 17. Comparison of harvest date and duration of storage on average fumigation induced disorders for Growers 1 and 2
Pre-fumigation drenches

Research conducted in 2003 revealed that drenching fruit in 2% Stopit® prior to fumigation reduced fumigation scald and internal browning, while drenching in 2% ascorbic acid reduced the incidence of Stain. During the 2003 and 2004 marketing seasons (not into Japan) a grower encountered fruit rejections in the market place due to stain. In an attempt to rectify this problem the use of Stopit® drenches or ascorbic acid in the hot water on the grading line were investigated. It was found that the Stopit® drenches washed off in the water dump on the grader and were not effective while the ascorbic acid was expensive. As a result, in 2004, two alternative compounds ascorbyl palmatate and an experimental food grade antioxidant (SHT2) were included in the trials.

In these trials stain was not encountered, so the effect of these materials on this disorder could not be determined. Ascorbyl palmatate was used, as it is commercially available, water soluble and cheaper than ascorbic acid. Unfortunately, it was found that its water solubility was not high and its use cannot be recommended without further investigation.

As for the 2003 season, it was found that drenching the fruit in Stopit® or ascorbic acid prior to fumigation resulted in a dramatically reduced appearance of fumigation scald (Figure 18). The other 2 alternative antioxidants had similar effects indicating equal efficacy. Unlike the 2003 season, however, it was found that none of the treatments had an effect on the appearance of internal browning (Figure 19). The reason for this different response in the two seasons cannot be explained from these trials.

Figure 18. Comparison of different fruit drenches on fumigation scald. Untreated control (UTC) Stopit® (Stop), ascorbic acid (AA), Potential new antioxidant (SHT2) and ascorbyl palmatate (AP). Bars represent 5% LSD
Pre-harvest colouration treatments

An analysis of the fruit from the shaded, lower levels of the trees compared to the sunny exposed positions identified that the exposed fruit were significantly heavier, redder, had higher sugars and greater fruit firmness with less flecking (Table 10). Fumigation damage was not encountered in this trial which was fumigated after 3 weeks of storage at 0°C.

Table 10. The influence of fruit tree position on fruit quality.

<table>
<thead>
<tr>
<th>Fruit weight (g)</th>
<th>greater 60% red (%)</th>
<th>flecking (0-10)</th>
<th>TSS (%)</th>
<th>Firmness (kg)</th>
<th>Fumigation Scald (%)</th>
<th>Stain (%)</th>
<th>Internal Browning (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom of tree</td>
<td>156 a</td>
<td>19.3 a</td>
<td>3.6 a</td>
<td>10.4 a</td>
<td>7.30 a</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Top of tree</td>
<td>206 b</td>
<td>38.3 b</td>
<td>3.1 b</td>
<td>11.5 b</td>
<td>7.54 b</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

For fruit colour no treatment effects were found for fruit located in the top portion of the trees (data not shown). In the fruit in the lower region of the trees, it was found that abscisic acid was the only treatment that statistically increased the percentage of red fruit over the untreated control (Figure 20). Importantly, all other treatments, while not being statistically different from the untreated controls, appeared to also act in a positive manner although further research is needed to verify this observation.
For fruit size, it was found that abscisic acid, KTS and Quinmerac all led to significantly smaller fruit when compared to the untreated control while the sucrose treatment led to increased fruit size (Figure 12).

Flecking is an important skin defect that can lead to substantially reduced pack outs of high grade fruit. In these trials it was found that the degree of fruit flecking was related to the treatment effects on fruit size (Figure 21). The exceptions were Sucrose and Quinmerac, both of which appeared to have reduced flecking considering the treatment effects on fruit weight.

This trial has revealed that abscisic acid leads to improved fruit colour but smaller fruit. Quinmerac leads to smaller fruit with less flecking and possibly an improvement in fruit colour. Sucrose leads to larger fruit without an associated increase in fruit flecking and possibly an improvement in fruit colour over the untreated control.
Conclusions 2004

These experiments have highlighted that the storage conditions prior to fumigation have a determining effect on the ability of the fruit to resist damage by methyl bromide fumigation. It is essential to store the fruit at 0°C, storage at 5°C does not eliminate the sensitivity of the fruit to fumigation damage. This indicates the necessity to closely monitor the temperature of the cold storage room and suggests that storage in a room in everyday use may not provide enough cold treatment to control the appearance of fumigation injury. The second component of the storage conditions found to be important, was the duration at 0°C. During the 2004 season it was found to be necessary to store the fruit for a minimum of at least 3 weeks prior to grading, packing, tempering and fumigation. It is suggested that fruit should be store for 4 to 5 weeks prior to preparation for export as this period will allow sufficient time to overcome fumigation damage while maintaining honey core in the fruit.

The results for the effect of maturity on fumigation damage were the same as previous seasons, it was found that earlier harvested fruit were less susceptible to fumigation damage. Due to the fumigation operations, however, it was always a concern that the fruit from early harvests had been stored for a longer period prior to fumigation and it is now apparent that the increased storage duration at 0°C for the earlier harvests provided a significant level of protection from fumigation damage. In the storage temperature and duration trials, tree ripe fruit were used and one of the growers was from an orchard with a history of severe fumigation injury. In these trials, however, it was found that these susceptible tree ripe fruit could be safely fumigated if stored at 0°C for more than 3 weeks prior to grading, tempering and fumigation. This indicates that provided fruit are stored for a designated period then tree ripe fruit may be safely fumigated and marketed in Japan. It should be noted that these results are for one season only and since there is marked seasonal difference in response of fruit to fumigation these trials should be repeated before commercial implementation.

As for the 2003 season, it was found that drenching the fruit in Stopit® or ascorbic acid dramatically reduced the incidence of fumigation damage. Due to problems encountered in incorporating these treatments into a commercial operation two alternative antioxidants were successfully trailed in 2004 and their incorporation into a commercial packing shed is being explored.

Fruit colour is essential for maximising returns to growers. In the trial exploring the effect of several spray materials on fruit colour it was found that only abscisic acid confidently increased fruit colour. All other treatments increased colour but to a less reliable extent. One negative aspect for the commercial adoption of abscisic acid for increased colour is that it led to smaller fruit. The only treatment that led to larger fruit was application of sugar which also appeared to not aggravate the appearance of flecking, a late season for of fruit russet.
2005 Experimental trials

Methods

Fumigation protocol
For all experiments outlined below, the following protocol was used in the fumigation procedures. Unless otherwise stated, experimental fruit were stored in boxes at 0°C prior to fumigation, then removed from cold storage and left at ambient temperatures (approx. 10°C) for 3 days prior to tempering. The fruit were tempered at 17°C for 24 hours and then fumigated alongside commercial shipments of fruit destined for Japan on June 12, approximately 8 weeks after harvest. The fumigation chambers were operated at between 17°C and 20°C, with a target MeBr concentration of 48gm⁻³ for 2 hours, followed by four hours of ventilation. After fumigation, all fruit were cooled to a target temperature of 0°C. Experimental fruit were placed into a coldroom for simulated transport (2°C for 3 to 6 weeks), then assessed for fumigation damage. The fruit were examined for external damage and then assessed for internal damage. The number of fruit affected by scald, stain, internal browning and core rots were recorded. The disorders were scored in a qualitative manner, fruit were assessed as having (i) no sign of the disorder (none), (ii) evidence of the disorder that would not be considered commercially significant (minor), or (iii) evidence of the disorder that would be considered commercially significant (severe). Unless otherwise stated, the results presented are based on the sum of the minor and severe categories.

Interactions between SmartFresh® and methyl bromide fumigation of apples.
A sample of between 114 and 120 ‘Fuji’ apples were collected during 4 separate commercial applications of SmartFresh®. These were divided and half placed in the room receiving SmartFresh® application while the other half were stored in a cold room (control). After application the SmartFresh® fruit were removed and stored alongside their control partners in a cold room. At the time of commercial fumigation of apples for Japan these samples were divided and half treated with methyl bromide alongside a commercial shipment of fruit. All fruit were then stored in a cold room for 4 weeks prior to assessment for fumigation damage as described above.

Controlled Atmosphere Temperature (CATTS) as an alternative to methyl bromide fumigation of ‘Fuji’ apples.
CATTS involves heating fruit in 10% CO₂ and 1% O₂ environment from 20°C to a core temperature of 45°C at 12°C / hour and holding this temperature for 10 minutes. In these trials 10% O₂ was used due to technical difficulties.
In order to determine a potentially safe rate of fruit heating, fruit skin temperatures were monitored in an orchard prior to harvest to determine naturally occurring temperatures and rate of heating experienced by fruit in the orchard environment. Two eight channel data loggers were fitted with Phillips 2322-640-63332 NTC thermistors (3mm diameter) attached to 3m leads. These were inserted just under the skin of ‘Fuji’ apple trees from 10 March till 25 March 2005. Two thermistors per logger were placed just under the skin of shaded fruit.

Two CMTS cabinets, each with two CMTS chambers were constructed and used (Figure 22). The chambers were 250 litre (510w x 690h x 710d mm) airtight units with a 30mm port hole in the rear and a airtight door to the front. Each unit had a 1200 watt heating element and a fan above the heating element to pass the air up the back of the chamber, through the shelves and back down the front. This fan provided greater than 1.5m/sec of airflow across all the shelves. The chambers were fitted with an independent digital thermostat for air temperature control and rate of heating was controlled through a variable power device to the elements.

Initial testing showed that the cabinets were air tight, however, with the first test run the first chamber failed to seal correctly so for remaining runs plastic was placed across the door (Figure 23). In total 3 trays, each with 20 fruit, were available for experimentation in each chamber.
The data loggers used in the field were used to record the core temperature of 1 fruit on each tray and the air temperature in the cabinet. In addition a similar thermistor was inserted into the core of a fruit on the middle tray and each chamber was fitted with a humidity sensor (Farnell 732-849). These two additional transducers (core temperature and humidity) were coupled to a computer through a Measurement Computing minilab 1008 a to d system. A computer program monitored fruit core temperature and turned the chamber off when the CATTS treatment was completed. This system also activated a small humidification system inside each chamber (visible in Figure 23) to maintain air relative humidity above 80%. The CATTS control screen and a typical output screen are shown in Figure 24.

Bottled nitrogen was initially used to reduce oxygen in the chamber then bottled carbon dioxide added to raise CO$_2$ to the desired level. Chamber gas concentrations were manually monitored using a Besseling portable O$_2$ / CO$_2$ analyser. During the first test run
a leak in the chamber resulted in nitrogen wastage and there was insufficient remaining nitrogen to reach the 1% oxygen target for the remaining chambers. Consequently a new target of 10% oxygen was set for the remaining CATTS runs which needed to be conducted over the following 24 hours, during the weekend.

At commercial harvest a sample of ‘Fuji’ were harvested from a commercial orchard and stored in a cold room until the time of commercial fumigation of apples for Japan. Forty eight (48) fruit were then allocated to a control treatment, 48 to methyl bromide fumigation and 48 were treated with CATTS. This was replicated 6 times giving 288 fruit per treatment. After treatment the fruit were cooled to 1°C and stored for 16 days to simulate shipment to Asia. After simulated shipment fruit were assessed for incidence of ‘Fuji’ stain, fumigation scald, greasiness and internal browning. Data was analysed by analysis of variance and means separated by LSD at $p = 0.05$

The influence of grader waxing and drying operations on the appearance of methyl bromide fumigation damage

At the time of commercial grading and packing of apples destined for Japan packing sheds were inspected and approximately 50 ‘Fuji’ fruit were removed from commercial grading lines just prior to the application of wax and another sample of 50 fruit was removed from the outlet of the wax drying tunnel approximately 3 minutes later. This was performed on three occasions from 2 grading lines. After collection fruit were stored in a cold room and then fumigated with methyl bromide alongside a commercial line of fruit destined for Japan. The fruit were then stored in a cold room for 6 weeks prior to assessment for fumigation damage.

The effect of brand of wax on damage due to methyl bromide fumigation or CATTS treatment

At commercial harvest ‘Fuji’ apples were collected from a commercial orchard and stored in air till the time of commercial fumigation for Japan. Ninty Fruit were then allocated to each of 4 wax treatments. Untreated, Castle Chemicals Canauba Ultra, Decco apple Lustre and Campbell Canauba Xtra. The wax material was applied by heating the surface of the apple in 35°C water for 15 seconds (as occurs on a commercial grading line), dried with a cloth (normally blasted with warm air) and then the wax was rubbed on with a damp cloth. After application fruit were placed in a 60°C forced air chamber for 4 minutes to simulate a tunnel dryer on a grader. Fruit in each of the wax treatments was then divided and half treated with methyl bromide alongside a commercial line of fruit and the other half exposed to CATTS treatment. This process was repeated giving two replicates of 8 treatments.

After methyl bromide or CATTS treatment the fruit were placed in a cold room for 6 weeks and then 1 week at room temperature prior to assessment for skin and flesh damage as well as fruit quality.

Fruit was initially visually assessed for gloss appearance and rated on a 1 to 5 scale where 5 was very glossy. They were then visually assessed for greasiness on a 0 to 10 scale where
0 is fresh feeling. Fruit were assessed for ‘Fuji’ stain prior to measurement of fruit firmness on an automated machine and fruit sugars were measured on juice collected from the firmness measurement. Data was analysed by factorial analysis of variance and means separated by F value (CATTS vs methyl bromides) or LSD (wax treatment) at $p = 0.05$.

Chemical colouring agents to improve ‘Fuji’ red colour prior to harvest

High packout rates are essential for economic returns to apple growers. The Japanese market demands ‘Fuji’ apples with close to 100% of the skin red coloured leading to poor packout rates. In the trial reported here seven potential colouring agents and selected combinations of these agents were applied to a commercial orchard of ‘Fuji’ apples destined for Japan. The treatments were applied to individual trees on 3 occasions at weekly intervals prior to harvest. Spray application was at 1250L/Ha. Treatments were an untreated control, Bapsol® (6-Benzylamino purine at 900ml/100L), iii) Sucrose (1kg/100L), Abscisic acid (30g/100L), Quinmerac® (an auxin at 20g/100L), Maxim® (an auxin at 20g/100L), Ethrel® (30ml/100L), Sucrose + abscisic acid, Sucrose + abscisic acid + Maxim®. These were applied to a young (about 4 year old) ‘Ogura Fuji’ trees growing on an upright trellis system and planted 1 metre apart. The trial was replicated six times. At commercial harvest a sample of 20 fruit from the lower portion of each tree was harvested and stored in a cold room until the commercial fumigation of apples destined for Japan. These fruit were then fumigated with methyl bromide alongside a commercial shipment and stored for 5 weeks in a cold room prior to fruit analysis for fruit colour, fumigation damage and fruit quality. Data was analysed by the analysis of variance and means separated by LSD at $p = 0.05$.

Results and discussion

Interactions between SmartFresh® and methyl bromide fumigation of apples.

In these trials the application of SmartFresh to ‘Fuji’ apples did not lead to the appearance of any fruit damage such as internal browning. In addition, methyl bromide treatment did not result in the development of fumigation damage (Table 11). In order to determine the impact of SmartFresh® on fumigation damage it will be necessary to repeat these experiments until significant levels of damage are encountered in the control fruit.
Table 11  The effect of SmartFresh® treatment and Methyl Bromide on stain, fumigation scald, internal browning and fruit taste averaged across 4 grower lines

<table>
<thead>
<tr>
<th></th>
<th>Number of apples</th>
<th>Stain %</th>
<th>Fumigation Scald %</th>
<th>Internal Browning %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SmartFresh®</td>
<td>MeBr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UTC</td>
<td>Yes</td>
<td>116</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SF</td>
<td>Yes</td>
<td>119</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>UTC</td>
<td>No</td>
<td>114</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SF</td>
<td>No</td>
<td>120</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Controlled Atmosphere Temperature (CATTS) as an alternative to methyl bromide fumigation of ‘Fuji’ apples.

a) Field Skin Temperatures

Daytime temperatures of exposed fruit were commonly 5°C warmer than shaded fruit and maximum daytime skin temperatures were typically between 15 and 25°C (Figure 25). The maximum fruit skin temperature approached 35°C on 2 of the 16 days (12% of the days) and night time skin temperatures below 5°C occurred 5 times and were close to 0°C on 2 occasions. The average hourly rate of skin temperature change was typically 5°C with rates reaching between 10 and 15°C on 6 occasions. This suggests that for freshly harvest Tasmanian ‘Fuji’ apples placed in a CATTS chamber rates of temperature increase of 5°C per hour should present no problems and rates should be able to be increased to above 10 and below 15°C with safety. The target temperature of 45°C is of concern, however, as in these measurements fruit skin temperatures never exceeded 35°C and it is doubtful that core temperatures (not monitored) exceeded 20°C. Hence the final temperature of the CATTS treatment may lead to problems in the skin but there is an increased probability that it will lead to problems in the core of the apple. Further, as the CATTS treatment will be performed on stored fruit it is likely that fruit tolerance to high temperature will be reduced. In 2006 it is suggested that fruit core temperatures in the field be monitored.
Figure 25. The average fruit temperature of shaded and exposed ‘Fuji’ apples and the average hourly rate of heating and cooling.

b) CATTS versus methyl bromide

The temperature and humidity profile of the CATTS treatment (Figure 26) shows that humidity was held above 80% for the duration of CATTS treatment as desired. Air temperature rise was steep, at 29°C per hour and fruit core temperatures increased at 20°C per hour and lagged 30 minutes behind the air temperature. A core temperature of 45°C was reached after 150 minutes. At this time heating ceased but the chambers remained closed and under atmosphere for another 70 minutes before opening and venting. Initially the chambers were at 10.3:9.3% CO₂:O₂ and by the finish of the run, 2.5 hours later, they were at 7.8:10.1% CO₂:O₂.

Figure 26. Temperature and humidity profile of CATTS treatment

Under these test conditions the CATTS treatment more than doubled the incidence of ‘Fuji’ stain although there was no appearance of skin scald with the treatment (Table 12). Importantly is that CATTS treatment led to a dramatic reduction in fruit greasiness with all
fruit having a fresh feel after simulated marketing compared to 72% of the untreated fruit having a greasy feel. Hence, on the basis of feel the CATTS treated fruit were marketable while the untreated were not. While the increase in ‘Fuji’ stain in this trial was commercially tolerable, unfortunately the CATTS treatment, under these conditions, led to a massive and unacceptable increase in the level of internal browning of the fruit meaning the fruit were not marketable.

Two distinct internal browning symptoms were noted. The first symptom was a general diffuse browning in the outer cortex of the fruit reminiscent of senescent breakdown or chilling injury (Figure 27). The second symptom was a radial browning associated with the vascular bundles and for some fruit both symptoms were present.

Table 12. The effect of methyl bromide fumigation or controlled atmosphere and temperature (CATTS) treatment on ‘Fuji’ fruit quality.

<table>
<thead>
<tr>
<th></th>
<th>‘Fuji’ Stain*</th>
<th>Fumigation Scald</th>
<th>Skin Greasiness</th>
<th>Internal Browning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>1.8 a</td>
<td>0 a</td>
<td>72 a</td>
<td>0 a</td>
</tr>
<tr>
<td>Methyl Bromide</td>
<td>3.2 ab</td>
<td>0 a</td>
<td>2 b</td>
<td>0 b</td>
</tr>
<tr>
<td>CATTS</td>
<td>5.4 b</td>
<td>0 a</td>
<td>0 b</td>
<td>35 b</td>
</tr>
</tbody>
</table>

* $\sqrt{(x+1)}$ transformation used. Means within a column not different by LSD, $p=0.05$.

Methyl bromide fumigation did not increase the incidence of fumigation scald or internal browning (Table 12). There was a slight but insignificant increase in ‘Fuji’ stain with methyl bromide and, as for CATTS treatment, a dramatic reduction in the greasiness of the fruit. This reduction in greasiness and the absence of fruit damage meant that the methyl bromide fruit were still marketable.

![Figure 27. CATTS induced internal browning. Left diffuse, centre radial, right both forms of internal browning.](image)

**Notes on CATTS**

This was the first test run of the CATTS equipment and the treatment. It highlighted the problems that need to be overcome with the treatment. This trial work identified that the equipment had difficulty reaching 1% $O_2$ and could not provide adequate cooling after treatment and this will be corrected for 2006. In addition the rate of heating was greater
than desired. There is also a need to explore the impact of different levels of CO₂ and O₂ and different rates of heating on fruit quality as well as the duration at 20°C prior to treatment.

The influence of commercial grader waxing and drying operations on the appearance of methyl bromide fumigation damage

In this trial the level of appearance of fumigation damage was small and in the case of fumigation scald this was restricted to one line of fruit only. Averaged across the three grading lines there was no effect of the waxing and drying operation on the appearance of fumigation damage expressed as either scald or internal browning (Table 13). For ‘Fuji’ stain, however, all three graders gave similar results and there was a 90% probability that the wax and dry process led to a seven fold increase in Stain.

Of importance in this study is that one line of fruit encountered around 9% of the fruit with symptoms of fumigation scald despite the delay from harvest till fumigation. This same fruit suffered from a ‘speckled’ appearance not previously observed but similar to a problem encountered in a line of fruit shipped to Japan. A result from the 2003 fumigation trials, with methyl bromide fumigation soon after harvest, was that SmartFresh® lead to a dramatic increase in the appearance of fumigation scald. Both this trial and the problematic export fruit had been treated with SmarFresh® after harvest. This raises concerns about the usefulness of this product for fruit to be treated with methyl bromide.

<table>
<thead>
<tr>
<th>Waxing and drying of fruit</th>
<th>Number of fruit</th>
<th>Fumigation Scald %</th>
<th>Internal Browning %</th>
<th>Stain %</th>
<th>Water Core %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>151</td>
<td>4.17 a</td>
<td>0.87 a</td>
<td>1.13 a*</td>
<td>9.13 a</td>
</tr>
<tr>
<td>Yes</td>
<td>167</td>
<td>2.40 a</td>
<td>1.67 a</td>
<td>7.77 b</td>
<td>8.83 a</td>
</tr>
</tbody>
</table>

* Significant at \( p=0.10 \) (90% confident result is real)

The effect of wax material on damage due to methyl bromide fumigation or CATTS treatment

a) CATTS vs Methyl Bromide

The humidity profile of the CATTS treatment was above 80% for the duration of treatment as desired (Figure 28). The rate of fruit heating was reduced on the first experiment and closer to the target rate of heating, at 13°C per hour. Rate of core temperature increase was also 13°C per hour and lagged behind the air temperature by 24 minutes. CATTS treatment was completed by 180 minutes when the system was turned off and the door opened to increase the rate of cooling but the plastic seal was left intact to maintain the atmosphere.
This allowed the temperature inside the chamber to reduce at 2.6°C per hour for 7 hours prior to plastic removal. The initial atmosphere was 10.6:9.2% CO₂:O₂ and by the finish of the run, 3 hours later, levels were 7.9:11.0% CO₂:O₂.

As for the earlier trial it was found that the CATTS treatment led to a 10 fold increase in the level of ‘Fuji’ stain and critically increased the level of internal browning to commercially unacceptable levels (Table 14). In both instances the level of internal browning was around 35% indicating that this is not related to the rate of fruit heating but more to the final fruit temperature reached or an interaction with the rate of fruit cooling after treatment. Also supporting the earlier trial the CATTS treatment eliminated the appearance of greasy fruit. CATTS treated fruit felt fresh and had a fresh ‘squeak’ while methyl bromide fruit were moving from the tacky phase to the slippery phase of greasiness development. On the basis of greasiness the CATTS fruit were still marketable. Unfortunately the CATTS treatment was also observed to reduce the effect of the wax treatments and the fruit did not look as glossy although some of this may be attributed to the lack of greasiness. There was no effect of CATTS treatment on fruit firmness although the treatment reduced the level of fruit sugars.

Table 14. The effect of methyl bromide or CATTS treatment on damage of apples

<table>
<thead>
<tr>
<th></th>
<th>Gloss 1 to 5</th>
<th>Greasy 1 to 10</th>
<th>Stain %</th>
<th>Browning %</th>
<th>Firm Kg</th>
<th>TSS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>MeBr</td>
<td>3.00 a</td>
<td>4 a</td>
<td>0.5 a</td>
<td>0.5 a</td>
<td>6.38 a</td>
<td>13.6 a</td>
</tr>
<tr>
<td>CATTS</td>
<td>1.88 b</td>
<td>0 b</td>
<td>5.5 b</td>
<td>35.2 b</td>
<td>6.45 a</td>
<td>12.5 b</td>
</tr>
</tbody>
</table>
b) *Methyl bromide* treatment

All waxes significantly increased the glossy appearance of the fruit (Table 15). There was no differences between any of these commercial treatments. The wax treatments all appeared to increase the level of greasiness. While there is no statistical differences with the untreated fruit it is pertinent to note that a greasiness level of 3 indicates that the fruit are tacky while a score of 5 indicates that they were slippery. The wax treatments did not appear to affect the level of ‘Fuji’ stain, internal browning, firmness or sugars.

<table>
<thead>
<tr>
<th>Wax Product</th>
<th>Gloss 1 to 5</th>
<th>Greasy 1 to 10</th>
<th>Stain %</th>
<th>Internal Browning %</th>
<th>Firm Kg</th>
<th>TSS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castle Chemicals</td>
<td>1.0 a</td>
<td>2.6 a</td>
<td>0 a</td>
<td>0 a</td>
<td>6.39 a</td>
<td>13.8 a</td>
</tr>
<tr>
<td>Canauba Ultra</td>
<td>3.5 b</td>
<td>4.1 a</td>
<td>0 a</td>
<td>2 a</td>
<td>6.47 a</td>
<td>13.6 a</td>
</tr>
<tr>
<td>Decco</td>
<td>4.0 b</td>
<td>4.6 a</td>
<td>2 a</td>
<td>0 a</td>
<td>6.25 a</td>
<td>13.5 a</td>
</tr>
<tr>
<td>Apple Lustre</td>
<td>3.5 b</td>
<td>5.1 a</td>
<td>0 a</td>
<td>0 a</td>
<td>6.41 a</td>
<td>13.8 a</td>
</tr>
<tr>
<td>Campbell</td>
<td>3.5 b</td>
<td>5.1 a</td>
<td>0 a</td>
<td>0 a</td>
<td>6.41 a</td>
<td>13.8 a</td>
</tr>
</tbody>
</table>

Means in a column with a different letter considered different $p = 0.05$

---

c) *CATTS* treatment

Under the CATTS treatment the Apple Lustre appeared to maintain fruit gloss better than the other wax treatments (Table 16) although this wax was also associated with the highest incidence of ‘Fuji’ stain and had critically high levels of internal browning. The Castle Chemicals and Campbell wax products were associated with the lowest levels of ‘Fuji’ stain and had lower levels of internal browning that were not different from the unwaxed fruit. The Campbell product had the lowest level of internal browning of all the products including the untreated fruit and its level of internal browning was significantly less than that of Apple Lustre. These results suggest that the choice of wax product will be critical in successful CATTS treatment and this needs to be studied in more detail.

<table>
<thead>
<tr>
<th>Wax Product</th>
<th>Gloss 1 to 5</th>
<th>Greasy 1 to 10</th>
<th>Stain %</th>
<th>Internal Browning %</th>
<th>Firm Kg</th>
<th>TSS %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castle Chemicals</td>
<td>1.0 a</td>
<td>0 a</td>
<td>6 a</td>
<td>27.2 a</td>
<td>6.36 a</td>
<td>12.9 a</td>
</tr>
<tr>
<td>Canauba Ultra</td>
<td>1.5 ab</td>
<td>0 a</td>
<td>2 a</td>
<td>38.5 ab</td>
<td>6.46 a</td>
<td>12.4 a</td>
</tr>
<tr>
<td>Decco</td>
<td>3.0 b</td>
<td>0 a</td>
<td>10 a</td>
<td>52.1 b</td>
<td>6.50 a</td>
<td>12.8 a</td>
</tr>
<tr>
<td>Apple Lustre</td>
<td>2.0 ab</td>
<td>0 a</td>
<td>4 a</td>
<td>23.0 a</td>
<td>6.49 a</td>
<td>12.0 a</td>
</tr>
<tr>
<td>Campbell</td>
<td>3.0 b</td>
<td>0 a</td>
<td>10 a</td>
<td>52.1 b</td>
<td>6.50 a</td>
<td>12.8 a</td>
</tr>
<tr>
<td>Canauba Xtra</td>
<td>2.0 ab</td>
<td>0 a</td>
<td>4 a</td>
<td>23.0 a</td>
<td>6.49 a</td>
<td>12.0 a</td>
</tr>
</tbody>
</table>

Means in a column with a different letter considered different $p = 0.05$
Chemical colouring agents to improve ‘Fuji’ red colour prior to harvest

In the 2004 trial large central leader style trees were used and fruit from the lower shaded portions of the tree were assessed for material efficacy. In the 2005 season a younger orchard on a vertical trellis system with superior light penetration into the lower branches was used. This difference in growing system contributed to a greater level of fruit colouration in the lower portions of the tree (Figure 29) compared to the 2004 trial. Of interest is that in this trial all colouring agents led a significant improvement in the percentage of fruit with greater than 60% colour. In this trial Ethrel® was the superior colouring agent followed by Maxim® and abscisic acid (ABA), which also provided excellent results in 2004. In this trial fumigation damage was not observed and there were only minor effects of the treatments on other fruit quality attributes (data not presented).

![Figure 29. The effect of colouring agent of fruit colour of ‘Fuji’ apple](image)

Conclusions 2005

During the 2005 season methyl bromide damage of commercial shipments of fruit to Japan were minimal. This was due to the 5-8 week delay between harvest and fumigation identified from the 2004 research as being critical for successful fumigation of ‘Fuji’ apples. This effect was reflected in the trial results where little fumigation damage was observed.

There were no symptoms of fumigation damage detected in the SmartFresh® trials. Results from the commercial wax and dry trial as well as similar and unusual symptoms
encountered in one line of fruit exported to Japan raise concerns that this material may lead to a new type of skin fumigation damage and fumigation scald even on fruit that has been stored for 5 weeks prior to fumigation. The use of this material on fruit destined for Japan should be discouraged until the precise interactions are known.

CATTS treatment as an alternative to methyl bromide may become an eventuality, however, under the sub optimal conditions used this season this treatment led to severe fruit damage which needs to be practically overcome prior to full scale trials and trials using insects. The CATTS treatment was found, however, to make greasy fruit fresh feeling and this feature continued after 5 weeks of simulated transport and one week of storage at room temperature. This aspect of the treatment needs to be studied in more detail to ascertain if a component of this treatment can be incorporated into a commercial system for use with problematic fruit.

As identified in an earlier study ‘Fuji’ stain is aggravated by the waxing and drying procedure on fruit graders and this equipment needs to be optimised to reduce its impact on the appearance of stain.

For methyl bromide treatment there appeared to be no difference in the three waxes although stain, fumigation scald and internal browning was not apparent in these fruit. The CATTS treatment stimulated a severe response from the fruit and it was identified that Apple Lustre doubled the level of internal browning while Campbell’s Canauba Xtra may have reduced stain and had minimal impact on the level of internal browning.

All the colouring agents tested in 2005 resulted in an increase in the packouts of the fruit. Hence their use for improving fruit colour could be promoted to industry. Unfortunately no stain, flecking or fumigation damage was observed in this trial such that the impact of these materials on fumigation damage cannot be determined.
**Project conclusions**

This project, in conjunction with other related projects, has studied factors impacting on successful methyl bromide fumigation of ‘Fuji’ apples destined for Japan. The project came into existence due to unacceptable and non sustainable levels of fumigation damage being encountered in commercial shipments of fruit in 2001, 2002 and 2003. During this period the number of containers exported to Japan reduced from over 40 to none planned in 2004. As a direct result of this project one experimental container was successfully shipped in 2004 and this was increased to eight successful containers being commercially fumigated, shipped and marketed in 2005.

A complicating factor in this project was the identification of three different symptoms of fumigation damage being fumigation scald, internal browning and aggravation of ‘Fuji’ stain. The level of damage caused by each of these varied with season as did the reason for fruit rejections in Japan.

As part of this project many trials were conducted and many factors impacting on the appearance of fumigation damage were identified. It was found that earlier harvests of fruit were less prone to damage as were fruit that had been drenched in DPA (not allowed in Japan), antioxidants such as ascorbic acid or calcium chloride as Stopit®. The use of reflective cloth to improve fruit colour or colouring agents did not appear to be associated with an increase in the level of fumigation damage. The use of SmartFresh® led to severe fumigation scald in 2003 but not in 2004 or 2005 although a new fumigation damage symptom appeared on a SmartFresh® line of fruit in 2005 raising concerns about the use of this material on ‘Fuji’ apples to be fumigated with methyl bromide. It was found that commercial fruit waxing and drying operations increase fumigation damage. In 2003 the application of wax resulted in an increase in fumigation scald from 5 to 25% and in 2005 the operation led to a 7 fold increase in ‘Fuji’ stain.

The significant finding pivotal to the successful fumigation and export of ‘Fuji’ apples was the impact of storage duration and temperature. In 2003 a pre-fumigation storage temperature of 12°C increased fumigation scald from 5 to 35% and in 2004 a storage temperature of 5°C did not reduce fumigation scald while 0°C almost eliminated it. It was found that fruit need to be stored at 0°C for a minimum of 5 weeks to reduce damage, even on mature fruit, to commercially acceptable levels. Storage at 5°C is not effective such that coldrooms used on a daily basis should be avoided and fruit should not be out of coldstorage for longer than necessary as this reduces the storage time at 0°C. As a result of this finding an experimental container of fruit was successfully fumigated and marketed, after 7 weeks of storage, in 2004 and this provided industry with enough confidence to recommence shipments in 2005. In 2005 commercial fumigation operations were delayed till 8 weeks after harvest.

In 2005 investigations were initiated into CATTS (controlled atmosphere by temperature) disinfestation of fruit as an alternative to methyl bromide. This project will continue in
2006. One interesting result from this study is that the CATTS treatment eliminates the appearance of greasy fruit in the marketing chain.

References


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