Overcoming fumigation damage of apples destined for Japan

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Dr Gordon S Brown, Dr Lisa Schimanski and David Jennings

September 2004

Final Report AP03038 - Overcoming fumigation damage of apples destined for Japan
Milestone 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 developed and monitored an operations manual to minimise damage and conducted experiments to determine the precise cause of the problems with the view of developing a protocol to eliminate fumigation damage in future shipments.

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Summary

Tasmania gained access to the Japanese market for ‘Fuji’ apples in 1999. Initially, small volumes of apples were marketed in Japan, however since 2001 there has been considerable fruit losses due to fumigation damage. This damage has expressed itself as fumigation scald and internal browning. In addition, it has been identified that the fumigation process aggravates ‘Fuji’ stain.

Since 2001 research has been conducted to identify and verify the possible causes of the damage, develop operations manuals to minimise damage and to update the operations manual to reflect current research and commercial findings.

In the 2004 project(s) the operation manual was updated and distributed, key research was conducted to assist in overcoming damage in future years and commercial activities were monitored.

The research identified that storage temperature and duration after harvest and before fumigation is critical for minimising the appearance of fumigation damage. It was found that for the 2004 season fruit had to be placed in 0°C for a minimum of 3 weeks to reduce damage to acceptable levels. 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 is due to the increased storage time at 0°C for these earlier harvested fruit. It was concluded that if the correct storage temperature and duration were applied then tree ripened fruit, with high levels of water core, could be fumigated with minimal damage.

The effect of different postharvest drenches again highlighted that 2% Stopit® or 2% ascorbic acid eliminates fumigation scald. This research also identified that other antioxidants are also effective and trials are currently underway to investigate commercial application methods.

A trial was conducted to investigate the effect of different pre harvest sprays on fruit quality. It was found that abscisic acid increased colour but decreased fruit size while sugar increased fruit size and appeared to have little effect on a form of russet called flecking. Flecking was associated with fruit size, it is not clear whether these were directly related.

The operations manual has proved an invaluable tool to growers/packers sending fruit to Japan (The operations manual is attached at the end of this document), as it has highlighted the key areas of concern in terms of damage, and allowed growers to minimise the potential for commercial damage.

Two of the major improvements as a direct result of previous work with the Hobart Cold Storage Centre, who conduct the fumigation, was the implementation of 2
ventilation cycles after the fumigation run to increase the efficiency of MeBr removal from the product, and the introduction of force draft cooling after fumigation for greater temperature control.

The operations manual was distributed to all growers and other organizations involved in the fumigation and logistics of export. Initially, exports were cancelled due to the level of damage detected in the first experimental fumigation, however, they were initiated again after the positive results from the second fumigation date. The commercial fruit were fumigated after 7 weeks of storage at 0°C and no problems were encountered in Japan. Based on this a marketing plan is being developed for 2005 using the results from this research and successful commercial outcome.

Introduction

‘Fuji’ apples have been exported from Tasmania to Japan since 1999, using a fumigation protocol against codling moth, of 48 gm\(^{-3}\) methyl bromide (MeBr) for 2 hours at a fruit temperature of 17°C. Fumigation damage developed during transport in the 2001, 2002 and 2003 seasons with predominantly fumigation scald in 2001 (Schimanski et al. 2001) and 2003 (Schimanski et al. 2003) and internal browning in the 2002 (Brown et al. 2003) season. In addition it was found that MeBr fumigation caused an increase in the percentage of fruit expressing stain symptoms in the 2002 and 2003 season (Brown et al 2003 and Schimanski et al. 2003). These disorders have caused major restrictions in the marketability of fruit and it is therefore necessary to control these problems if the market is to be maintained. For three years the supply chain of ‘Fuji’ apples destined for Japan has been studied to identify the potential impact of each step on the appearance of fumigation damage and to research potential methods to overcome this problem.

The aim of previous research was to study pre-harvest and post-harvest activities with the potential to have an impact, after MeBr fumigation, on (i) internal browning (ii) scald and (iii) ‘Fuji’ stain. (i) Internal browning after MeBr fumigation was a major cause of financial loss in the Tasmanian ‘Fuji’ export programme in 2002. Based on the results of project AP01045, it was hypothesised that the underlying cause of the disorder was increased fruit respiration rate after removal from post-fumigation cold storage. The major factors associated with this disorder in the 2002 trials were fruit maturity, waxing and the amount of time fruit remained out of the cold storage before fumigation. These factors were investigated further in 2003 under project AP02039. From this research, conducted in the 2003 export season, it was concluded that the more mature the fruit the greater the susceptibility to these disorders, pre-fumigation storage temperatures of approximately 5 °C may be associated with the lowest rates of the disorders, pre-fumigation drenches such as Stopit®, and ascorbic acid may be effective against scald and stain, and waxing of the fruit increases the incidence of internal browning and scald.
(ii) Scald after MeBr fumigation was observed in 2001 and again in 2003, it appeared to be associated mainly with the green side of the fruit and was thought initially to be predominantly due to condensation in the tempering rooms and poor transport conditions. The quality assurance (QA) procedures introduced in 2002 appeared to minimise the occurrence of 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 a fruit physiological response to fumigation and it was shown that the problem was more pronounced on more mature fruit, in fruit that had been waxed and that antioxidant pre fumigation drenches minimised the problem.

(iii) ‘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 still 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 in the 2003 research to be a physiological problem with increased incidence in more mature fruit and after the fruit has passed through the 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 for project AP03038 was to confirm the earlier findings of the influence of harvest maturity and the influence of storage temperature and duration on the appearance of these problems. Research conducted as part of project AP02039 included the influence of antioxidant drenches and the effect on stain and fumigation damage. Also reported here for completeness is research funded by Scientific Horticulture on preharvest treatments with a range of chemicals to improve fruit colour and their effect on stain and fumigation damage.

**Experimental trials**

**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 before fumigation 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 two ventilation cycles. After fumigation, all fruit were placed in a 0°C room, using a forced draft cooling system. Experimental fruit were placed into a
re refrig erated container for simu lated 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 (Figures 1 to 3) 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.

Figure 1. Fumigation scald on a ‘Fuji’ apple after fumigation with MeBr.  
Figure 2. Internal browning of a ‘Fuji’ apple after fumigation with MeBr.  
Figure 3. Stain on a ‘Fuji’ apple after fumigation with MeBr.

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 protocol stated 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 (May 7 2004) and assessed as per the fumigation protocol stated above. Data for the means at each harvest was analysed using a split plot ANOVA.
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.
**Experimental results**

Storage temperature and duration from harvest prior to fumigation

**Grower effects**
Growers 1 and 2 harvested their fruit within a few days of each other (Table 1) 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 2). 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. 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 the influence of maturity is more important than Smartfresh treatment. These results indicate that fruit that is picked at the correct maturity 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>
<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>
</tbody>
</table>
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 4) 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.

Fumigation scald (Figure 1) was found to adversely affect commercial shipments to Japan in 2001 and again in 2003. Research conducted in 2004 has identified that this fumigation damage is related to storage temperature and duration (Figure 5). If fruit were stored at 0°C unacceptable levels of fumigation scald were encountered after one week of storage, however, scald was observed in 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 drop in the appearance of this problem (Figure 6). 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.

Neither storage temperature nor duration in storage prior to fumigation were associated with changes in the level of stain (Figure 3) in this trial (data not presented).
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 7). 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.

![Graph showing the effect of harvest date on fumigation induced disorders for 4 growers](image-url)

**Figure 7.** The effect of harvest date on the average fumigation induced disorders for 4 growers
Fruit maturity and 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, with the storage duration data, using the weeks from harvest till fumigation as the common factor (Figure 8). This revealed a close association between the two data sets, indicating that the earlier conclusions for the effect of harvest date on fumigation damage may have been due to the effect of storage duration at 0°C on fumigation damage. 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.

![Figure 8. Comparison of harvest date and duration of storage on average fumigation induced disorders for Growers 1 and 2](image)

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 it was desired to investigate other potential materials in the 2004 trials. Hence in 2004, two alternative compounds ascorbyl palmate 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 palmate 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 9). 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 10). The reason for this different response in the two seasons cannot be explained from these trials.

Figure 9. Comparison of different fruit drenches on fumigation scald. Untreated control (UTC) Stopit® (Stop), ascorbic acid (AA), Potential new antioxidant (SHT2) and ascorbyl palmate (AP).
Figure 10. Comparison of different fruit drenches on internal browning. Untreated control (UTC) Stopit® (Stop), ascorbic acid (AA), Potential new antioxidant (SHT2) and ascorbyl palmatate (AP)

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 3). Fumigation damage was not encountered in this trial which was fumigated after 3 weeks of storage at 0°C.

Table 3. 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>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. 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.
Figure 11. Comparison of different pre-harvest sprays on fruit colouration for fruit close to the ground. Bars represent 5% LSD values potassium thiosulphate (KTS) and absciscic acid (ABA)
For fruit size, it was found that ABA, 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 12). The exceptions were Sucrose and Quinmerac, both of which appeared to have reduced flecking considering the treatment effects on fruit weight.

![Figure 12. Comparison of different pre-harvest sprays on fruit weight and fruit flecking. Upward bars represent 5% LSD values for fruit weight, downward bars represent 5% LSD for flecking.](image)

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.
Experimental conclusions

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 trialed 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.
References


Schimanski LJ, Brown GS and Jennings D, (2003) Overcoming fumigation damage of Tasmanian ‘Fuji’ apples for Japan Project (project number AP02039)
Grower procedures for export of ‘Fuji’ apples to Japan

Operations Manual 2004

Preface

‘Fuji’ apples have been exported from Tasmania to Japan, by Apple Exports Tasmania Ltd. (AET) since 1999. This required the development of a fumigation protocol to prevent the entry of codling moth into Japan. The protocol developed uses 48 g/m³ methyl bromide (MeBr) for 2 hours at a core fruit temperature of 17°C (Williams 1994). Scald developed on several lines of fruit, after methyl bromide (MeBr) fumigation and transport to Japan, in the 2001 marketing season.

After the 2001 season, Scientific Horticulture was commissioned by AET to conduct a comprehensive investigation on the supply chain of ‘Fuji’ apples exported to Japan. The aim of this investigation was to examine the potential impact of each step in this chain on the appearance of scald. Due to changes in grower/packer procedures and fumigation practices there was no superficial scalding of fruit in 2002. However, ‘Fuji’ stain and internal browning did occur in this season.

‘Fuji’ stain, a brownish discolouration of the skin it can occur in large areas as shown in the photo (Photo 1) or as smaller circular marks across the surface of the apple. This disorder occurs prior to fumigation however the fumigation process aggravates it.

Internal browning is a browning of the flesh of the fruit around the vascular bundles (Photos 2 & 3) in its severe form it looks similar to CO₂ injury. This disorder may not become apparent until 7-14 days after fumigation, therefore it is difficult to detect before transport to export markets.

Photo 1. ‘Fuji’ stain

Photo 2. Severe internal browning of a ‘Fuji’ fruit due to MeBr.

Photo 3. Mild internal browning of a ‘Fuji’ fruit due to MeBr
Aims of this manual

This manual is designed to:
- Improve data recording
- Increase the quality of export grade ‘Fuji’ Apples
- Improve maturity assessment of ‘Fuji’ apples
- Provide for an even temperature change in the apples with minimal impact on fruit quality
- Improve the logistics of the export operation (between Growers, HCSC+, AQIS*, MAFF**, AET++)
- Minimise/prevent fumigation scald and internal browning in ‘Fuji’ apples destined for Japan.

+ Hobart Cold Storage Centre  * Australian Quarantine and Inspection Service
** Japanese equivalent of AQIS  ++ Apple Exports Tasmania
Module 1: Fruit Harvest

A pre-harvest spray of ‘Stopit’

There is anecdotal evidence that pre-harvest sprays of ‘Stopit’ may assist in the reduction of MeBr fumigation damage. Therefore it may be prudent to apply ‘Stopit’ sprays to any fruit with the potential for export to Japan.

Reflective cloth

‘Fuji’s’ for the Japanese market are often picked very mature to ensure maximum colour and honeycore. However, it has been ascertained that mature fruit are far more susceptible to internal damage. In order to maintain the colour of the fruit it is recommended that reflective cloth be used rather than leaving the fruit to mature on the tree for longer periods. The reflective cloth was found to significantly improve fruit colour, particularly on the green side of blush fruit, allowing the fruit to be picked earlier.

Fruit maturity

One or two days prior to anticipated commercial harvest growers should sample twenty fruit from each block. Alternatively, 4 fruit from each of 5 bins of fruit may be sampled within a few days of harvest. This fruit sampling should occur for every block that has potential for fruit to be exported to Japan. The recommended orchard sampling procedure is outlined below. Grower sheet 1: Fruit maturity should be filled in, indicating sample and actual harvest date of each block, firmness, TSS, development of honey-core (Honey-core should be recorded as the percentage of the transverse section of the apple that has developed honey-core.) and starch pattern (following Figure 1).

Fruit harvested overly mature are at greater risk of developing fumigation damage. It is a requirement of the Tasmanian ‘Fuji’ export programme that fruit be picked with a maturity index greater than 150. This will occur 1 week after a maturity index of 300.

Maturity index = \[
\frac{10 \times (\text{Firmness (Kg)} \times \text{Starch (\%))}}{\text{TSS (\%)}}\]

Indicative values:  
- Firmness > 8  
- TSS > 12%  
- Starch 30-60% (starch plate score 2-4, Fig. 1)

Fruit orchard sampling procedure: A random variation in fruit is required. Fruit are to be picked by walking up a row about two rows from the end of the block. Choose a fruit that is partially obscured in a tree just ahead of you, pick the fruit. Continue up the row, in this manner until you have reached the end of the row and collected twenty fruit. Walk to
the other end of the block and walk down a row about two rows in from the other end of the block, follow the same procedure as outlined above.

### Please note: Grower sheet 1: Fruit maturity should be faxed/sent through to Scientific Horticulture within 7 days of harvest.

**Fruit Picking**

In previous years fruit quality has been variable for ‘Fuji’ apples destined for Japan. In the 2001 season AQIS recorded an average of 30% damage (including bruising, stalk punctures and limb rub) of fruit and in some cases there were records of 100% damage.

- Growers are encouraged to line picking bins with bubble-wrap or cardboard when picking ‘Fuji’s’.
- Fruit destined for Japan is not to be picked when it is wet from rain or dew.
- There is anecdotal evidence that harvesting of fruit directly after a frost event may increase to risk of stain on the fruit. If the fruit is left on the tree for a further 4-5 days this risk is diminished.
- Good management practice and training of picking and grading staff are required to avoid fruit bruising.

## Grower sheet 1: Fruit maturity

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<th>TSS</th>
<th>Starch</th>
<th>Honey core</th>
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Figure 1: Starch pattern for 'Fuji' apples

- Score 1.1 Almost entire surface stained blue-black.
- Score 1.7 Staining absent from the core.
- Score 2.0 Staining absent from the core and about 10% of the cortex.
- Score 3.0 Staining absent from the core and the cortex to the vascular bundles.
- Score 4.0 Staining absent from the core and 50% of the cortex.
- Score 5.0 Staining absent from 90% of the cortex and mainly evident near the skin.

Module 2: Post-harvest cooling and packing of fruit

This module of the operations manual is concerned with the post harvest handling of the fruit in the pack house, from the initial cooling of the fruit to grading and despatch to the fumigation centre (HCSC). It is primarily designed for use by the packers of fruit and provides instructions on these operations.

Postharvest drenches
Research conducted during 2003 demonstrated that applying a 2% drench of Stopit® reduced fumigation scald from 30 to 2% and internal browning (due to fumigation) from 17 to 5% of the fruit. In addition this treatment led to a slight reduction in the incidence of stain. As a result it is recommended that fruit destined for Japan should be treated with a 2% Stopit drench following harvest. It should be noted that postharvest applications of Stopit are no longer on the label as there have been incidences of fruit damage especially when the material has been applied in conjunction with other drench materials such as DPA and to sunburnt fruit.

Fruit grading
- Prior to grading the fruit should be stored at 5 °C
- Picked fruit should be taken out of conventional storage 2-3 days prior to packing and then moved straight onto the fumigation centre after packing.
- In order to minimise bruising of the fruit, machinery should be operated at half normal speed when grading ‘Fuji’s’ destined for Japan. An evaluation of bruising points on the grading line can be performed by Graeme Thomson at the Victorian Department of Natural Resources and Environment (NRE), Knoxfield (03) 9210922 (see Appendix 1)
- Do not place stickers on the fruit
- Do not put bubble or cell air layers inside the boxes
- Do not use polyethylene liners.
- Colour and russet specifications are to comply with AET requirements
- There is to be no evidence of woolly aphid activity.
- Use adequate detergent in the fruit wash
- Use only a cold fresh water rinse (avoid recycled water).

Fruit packing
- Where a count requires the use of an A and a B tray, use two A trays and one B tray, plus an A cap tray of the same count (See carton specifications table below for details).
- Fruit should be placed diagonally on the fruit trays with the red side up.
- Please note from the table that counts 45, 36, and 30 should have a 240 mm high base with a normal lid.

<table>
<thead>
<tr>
<th>Carton Lid</th>
<th>Carton Base</th>
<th>Count name:3L</th>
<th>Tray name: 4L</th>
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<th>MKIV export pallet layout</th>
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<td>Japan 3L</td>
<td>215 mm</td>
<td>68</td>
<td>90</td>
<td>2X 23 A</td>
<td>63 cartons 9 layers</td>
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<tr>
<td>Japan 3L</td>
<td>240 mm</td>
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<td>15</td>
<td>56 cartons 8 layers</td>
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<tr>
<td>Japan 3L</td>
<td>240 mm</td>
<td>36</td>
<td>48</td>
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<td>56 cartons 8 layers</td>
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<tr>
<td>Japan 3L</td>
<td>240 mm</td>
<td>30</td>
<td>40</td>
<td>10</td>
<td>56 cartons 8 layers</td>
</tr>
</tbody>
</table>

Carton specifications

- The net weight of the box should be 12.1 kg (no over packing or under packing).

  Please 'check weigh' cartons on a regular basis, as over packing can cause potential damage and problems with fitting pallets into the fumigation chambers due to height restrictions.

**Pallet construction**

Pallet stacking

- The AET specified pallet is the only pallet to be used in the packing of ‘Fuji’ apples for Japan. The dimensions for the Mark IV pallet to be used are 1165x1000 mm.
- Column stack the first 3 layers and then cross pattern.
- There is to be only one count per pallet unless advised by your exporter (See carton specifications table for the number of cartons per pallet).
- Thermocouples will be provided by Scientific Horticulture with installation instructions. One thermocouple is to be installed in each pallet destined for Japan, in the manner described in the instructions. This needs to be located in the core of an apple at the centre of the pallet.

Pallet strapping

- The corner posts must start from 50mm down the pallet base to secure the boxes to the base.
Grower procedures for export of ‘Fuji’ apples to Japan

- Pallets should be strapped in the following manner to ensure that quarantine inspections can be accomplished efficiently:
  (1) The bottom strap is to be at the base of the bottom carton.
  (2) The middle strap is to be placed at the base of layer 5.
  (3) The top strap is to be placed 25 mm (1 inch) above the base of the top layer.
  (4) Don't over-tighten strapping to the point where the corners posts distort.
  (5) Costs may be incurred if re-strap ping of the pallet is required.

Pallet labels
- AET will supply each exporter with special adhesive labels. These have been printed with the same identification number on four labels and are to be applied to the bottom right carton of all 4 pallet corners (see Appendix II).
- The quantity of each count must be repeated on all four labels

Post packing storage and despatch
- The AET Hobart coordinator at the fumigation centre (HCSC) will organise despatch of fruit. Brian Anning is the coordinator in 2002, his contact details are 0413 597 846
Grower procedures for export of ‘Fuji’ apples to Japan

Procedures after packing
If fruit are placed back in refrigeration after grading they should be stored at 5 °C. Picked fruit should be taken out of conventional storage 2-3 days prior to packing and then moved straight onto the fumigation centre after packing.

Despatch procedures
- Three extra cartons of fruit need to be supplied with each grower consignment transported to HCSC. This will be used as replacement fruit for samples taken for inspection purposes during the fumigation process by MAFF, AQIS and Scientific Horticulture.
- Growers are required to fill in Grower Sheet 2: Post harvest cooling and packing, indicating date placed in cold storage, temperature of the cold room, date out of cold storage, date packed, date placed back into cold storage, date out of cold storage and date sent to HCSC.

Please note: Grower sheet 2: Post harvest cooling and packing, must be faxed/sent through to Scientific Horticulture at the time of fruit dispatch to HCSC to ensure eligibility of fruit for export.

- All transport arrangements will be made by the AET coordinator.
- The AET coordinator will advise of loading times to Hobart. Fruit will be organised to arrive at HCSC between 10am and 12 noon daily to ensure that fumigation schedules can be met.
- Please complete and send with each truck load the AET advice note. Showing individual pallet ID, pallet count and quantity (see appendix III).
Technology services provided by the Victorian Department of Natural Resources and Environment (NRE) have been used by a large Tasmanian apple packing company to minimize fruit being bruised during packing.

The Driessen brothers company was having problems with bruising in Golden Delicious and Pink Lady apples, which were limiting product quality and causing difficulties in grading.

An instrumented sphere, operated by Graeme Thomson of NRE’s Institute for Horticultural Development, was used to assess the Driessen packing line for sites likely to be causing physical damage to the fruit.

Mr Thomson explained that the sphere is passed, with the fruit, along the packing line, where it records the strength of any impacts. These may include drops in height and collisions with components of the conveying system. “Experience tells us which sites can potentially cause impact” he said. “The sphere is then run repeatedly through those sites to gain impact data and verify the overall importance of the site in causing damage. Bruising can often be prevented by using padding at these sites, generally at low cost.”

Hans Driessen said that the exercise of using the instrumented sphere had been worthwhile. “We found that damage was occurring at what we thought were unlikely places on the packing line” he said. “By fitting padding to the damaging points, we’ve been able to reduce bruising to very low levels and improve the quality of our product. It’s also made our apples much easier to grade.”

Mr Driessen also noted that other Tasmanian apple packers are interested in this service. Mr Thomson added that, apart from its use with apples, the instrumented sphere can also be used on grading and packing lines with products such as stone fruit and citrus.
### Appendix II

**AET Limited**  
**Japan Pallet Card**

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## Appendix III

Loading Date:  ……/……./…….
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Consignee: Apple Exports Tasmania Limited
Destination: Hobart Cold Storage Centre
Exporter: 
Packing Shed: 
Variety:  ………………………....

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**Grower procedures for export of ‘Fuji’ apples to Japan**

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**Grower sheet 2 - Post harvest cooling and packing:**

<table>
<thead>
<tr>
<th>Orchard name:</th>
<th>Storage</th>
<th>Grading and packing</th>
<th>Preparation for despatch</th>
</tr>
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<tbody>
<tr>
<td>Block</td>
<td>harvest date</td>
<td>date into cold storage</td>
<td>date out of cold storage</td>
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**Columns titled "date placed back into cold storage" and "date removed from cold storage" will not need to be filled out if you are following method 2 in the procedures after packing section (page 10 of the manual)**
Placement of thermocouples

(1) Thermocouples are to be located in the 5th layer from the base of the pallet.

(2) Place thermocouple in the middle carton of the cartons directed long-wise.

(3) The thermocouple is to go into the middle apple at the far end (toward the centre of the pallet) of the top layer within the carton.

(4) Each thermocouple is coated with an inch of blue plastic at one end. This end is to be pushed into the calyx end of the apple until you can not see any blue.

(5) Orientate the apple so that the calyx end of the apple faces toward the outside of the pallet, to allow for easy removal by pulling the thermocouple lead.

(6) Thread the thermocouple head through the outer ventilation hole of the base and the outer ventilation hole of the lid.

(7) Replace the lid and put the carton back into place with the thermocouple head hanging from the ventilation hole.

(8) Continue to build the pallet and place the corner posts and strapping.

(9) Tape the thermocouple lead (about 5-6 cm from the head) to the nearest corner strap with the coloured electrical tape supplied. Poke the head of the thermocouple back into the nearest ventilation hole to prevent it from being damaged. Place the electrical tape so that it runs the entire width of the corner post (i.e. can be seen from two sides of the pallet).
Module 3: Hobart Cold Storage Centre procedures for Fuji export to Japan

Abbreviations:
- AET = Apple Exports Tasmania
- HCSC = Hobart Cold Storage Centre
- AQIS/MAFF = Australian Quarantine and Inspection Service and the Japanese equivalent
- SH = Scientific Horticulture

Fruit receival
- Temperature of all fruit will be assessed upon arrival at the fumigation centre using the thermocouples installed at packing. Colder fruit will be placed to the back of the tempering room and warmer fruit to the front. This will minimise any potential ‘double-handling’ of the fruit and enable an estimate of the time needed for tempering of the fruit.
- Record the following information:-
  - Pallet numbers (AET + SH)
  - Delivery docket (AET to photocopy and provide to HCSC and SH)
  - The date/time of fruit received and placed into the tempering rooms (AET + SH)
  - Temperature (SH)
- One carton per day per grower needs to be put into a cold room on arrival at HCSC. A white, number 3 identifying label will be placed on this fruit. Date and time of arrival, consignment #, grower details will be recorded on the label (SH). Labels 1 and 2 will be filled out and placed on the remaining 2 extra cartons. After fumigation these fruit will be stored and assessed for fumigation damage prior to shipment arrival in Japan. (SH)

Tempering rooms
- One tempering rooms will be available in the 2004 season. A total 42 pallets of fruit will be in these rooms at any one time. Fruit will remain in the tempering room for 40-48 hours and will need to reach a target temperature of 17°C prior to fumigation.
- A data logger will be placed in both tempering rooms at the beginning of the season (20/5/02) to record temperature and humidity.
- The set point of the tempering rooms will be 19°C
- To satisfy the AQIS/MAFF inspections, fruit penetration probes will be used with a temperature of 17°C reached 2 out of 3 times. However, Scientific Horticulture will also record core temperature of the fruit. Scientific Horticulture will notify AET if any fruit has a core temperature below 12°C.
- The humidity in the tempering room will be monitored, if levels are above 60% the door to the tempering room will be opened a little to allow dry cold air into the room and release some of the moisture.

Fumigation chambers
- Record the following information:-
Grower procedures for export of ‘Fuji’ apples to Japan

- date/time and temperature of fruit into fumigation chamber (AQIS)
- MeBr dosage (AET + SCSC event recorder)
- 10.5 pallets will be loaded into each fumigation chamber at any one time.
- The chamber air volume is 55m$^3$ including ducting, at 53% capacity according to the maximum loading allowed in the protocol fruit can occupy 29.15m$^3$ or 11.4 pallets.
- The MeBr dose must be accurate and recording equipment fully functional.
- Accurate monitoring of MeBr levels within the chamber during fumigation and venting of fruit is essential (HCSC event recorder).
- Pallets must be left in the fumigation chamber for a minimum of two hours of active venting, before placement into the activated charcoal chiller.

**Blast Chiller**
- Record the following information:
  - date/time of fruit into the blast chiller (HCSC)
  - Temperature of fruit into the blast chiller (SH)
- HCSC will record temperature prior to removal from the blast chiller. Fruit is not to be removed from the blast chiller until thermocouples register 2°C ±2°C
- There is a risk that this target core temperature is too high. This will be reviewed after the 2002 season, once fruit susceptibility is known and research is completed.

**Inspection**
- HCSC to present pallets for inspection
- AET will provide assistance to inspectors in accessing the fruit from the pallets
- AQIS/MAFF will inspect fruit according to protocol and record the date/time of inspection. They will replace any fruit as necessary.
- Gather information for the phytosanitary certificates
- Provision of information to all relevant parties (AET + AQIS/MAFF)
- One QA carton / fumigation batch/grower to be removed and placed into coldstorage. This fruit will be available for domestic sale upon receival of fruit in Japan without incident (SH).

**Transport container**
- Record the following information:
  - The shipping container thermostat is to be set to give a maximum transport temperature of 0C. Check the shipping container thermostat temperature (AET/TOLL).
  - The shipping container is to be pre-chilled prior to loading. Check shipping container temperature prior to loading. (SH)
  - Date/time and temperature of fruit into the shipping container (SH).
  - Record the pallet numbers and any other relevant information for documentation (AET)
- Remove thermocouples from the pallets (SH)
- Present pallets to the container (HCSC), loading of the container (AET/TOLL)
- Place two data recorders into each shipping container (AET)
- Observe and verify container for import requirements. Fill out documentation as required (AQIS/MAFF)
- Construct phytosanitary certificates (AET), issue phytosanitary certificates (AQIS/MAFF).

**Please note:** The full completion of the “HCSC Fuji apple fumigation reports” including time and date will provide all of the information required (see attached HCSC sheet 5).
<table>
<thead>
<tr>
<th>Activity</th>
<th>Apple Exports Tasmania (AET)</th>
<th>Hobart Cold Storage Centre (HCSC)</th>
<th>AQIS / MAFF</th>
<th>Toll/Patrick's/ Maersk/ANL</th>
<th>Scientific Horticulture (SH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container Preparation</td>
<td>Contact shipping line and book the number of containers by size, destination and date.</td>
<td></td>
<td>Inspection and the issue of a certificate of quality and hygiene</td>
<td>Shipping line confirms the booking in writing and issues release numbers for containers</td>
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<td>Shipping line performs a check of the refrigeration plant in the containers at the docks, insect proofs and sets the temperature</td>
<td>Stevedoring company cleans the container</td>
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<td>Container transported to Hobart and the transport company checks for cleanliness and any damage</td>
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<td></td>
<td>Transport company checks temperature settings and installs Pardlow charts</td>
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<tr>
<td>Fruit pickup</td>
<td>Organise schedule for delivery to HCSC between 1-4 pm</td>
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<td>Pickup only in taut liners at predetermined time</td>
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<td></td>
<td>Remind packers about extra QA fruit required</td>
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<tr>
<td>Fruit receival</td>
<td>Verify and record advice transfer details. Photocopy and distribute copies to HCSC and SH.</td>
<td>Verify and record advice transfer details</td>
<td></td>
<td>Deliver fruit between 1-4 pm</td>
<td>Record pallet temperatures, date and time received</td>
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<tr>
<td></td>
<td>Record date and time of receival</td>
<td>Place into tempering room according to temperature</td>
<td></td>
<td></td>
<td>Label the 3 extra grower cartons 1,2,3</td>
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<tr>
<td>Activity</td>
<td>Apple Exports Tasmania (AET)</td>
<td>Hobart Cold Storage Centre (HCSC)</td>
<td>AQIS / MAFF</td>
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<tr>
<td>Tempering rooms</td>
<td></td>
<td>Monitor room temperature and humidity. Take corrective steps if necessary</td>
<td>Probe fruit and record temperature prior to removal from tempering room</td>
<td></td>
<td>Monitor room temperature, humidity and fruit temperature. Advise AET of fruit core temperatures if below 12° C</td>
</tr>
<tr>
<td>Fumigation Chamber</td>
<td></td>
<td>Move fruit from tempering room and load chamber with 10.5 pallets. Include one QA box/grower/chamber. Record batch numbers</td>
<td>Observe loading of chamber.</td>
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<td></td>
<td>Vent chamber, record venting start and finish times. Event recorder will monitor MeBr levels and times of activities</td>
<td>Observe chamber operation</td>
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<tr>
<td>Blast chiller</td>
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<td>Move fruit into blast chiller</td>
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<td>Monitor fruit temperatures in blast chiller</td>
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<td></td>
<td>Record date, time and fruit core temperature before removal. Advise AET if temperature is above 4° C</td>
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<tr>
<td>Activity</td>
<td>Apple Exports Tasmania (AET)</td>
<td>Hobart Cold Storage Centre (HCSC)</td>
<td>AQIS / MAFF</td>
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<td>Scientific Horticulture (SH)</td>
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<tr>
<td>Inspection</td>
<td>Provide all relevant information for phytosanitary certificates, Provide labour assistance for inspectors</td>
<td>Present pallets for inspection</td>
<td>Inspect fruit according to protocol, record date and time. Replace fruit as necessary. Provide copies of relevant documentation to AET and SH</td>
<td></td>
<td>Obtain copies of inspection reports remove 1 QA carton per fumigation batch / grower and place into coldstorage</td>
</tr>
<tr>
<td>Loading</td>
<td>Check container temperature, record pallet numbers and fill out other relevant documentation</td>
<td>Present pallets to container</td>
<td>Observe and verify container for import requirements. Fill out documentation as required.</td>
<td>Container despatched to HCSC</td>
<td>Record fruit temperatures and remove thermocouples</td>
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<td>Two mechanical recorders installed</td>
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<td>Provide at least one person to assist in the loading of the container, depending on arrangements with TOLL</td>
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<td>Construct the phytosanitary certificates</td>
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## HCSC Fuji apple fumigation report - 2002

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