National application of new techniques for scald control

Dr Robert Holmes
VIC Department of Primary Industries

Project Number: AP99010
This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the apple and pear industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of the apple and pear industries and Rohm & Hass.

All expressions of opinion are not to be regarded as expressing the opinion of Horticulture Australia Ltd or any authority of the Australian Government.

The Company and the Australian Government accept no responsibility for any of the opinions or the accuracy of the information contained in this report and readers should rely upon their own enquiries in making decisions concerning their own interests.

ISBN 0 7341 0859 1

Published and distributed by:
Horticultural Australia Ltd
Level 1
50 Carrington Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399
E-Mail: horticulture@horticulture.com.au

© Copyright 2004
National Application of New Techniques for Scald Control

Horticulture Australia Project
Number AP99010 (March, 2003)

Final Report
Simone Kreidl, Robert Holmes, John Lopresti, Ian Wilkinson, Peter Franz, Michael Rettke

Institute for Horticultural Development, Knoxfield
Department of Primary Industries, Victoria.
Horticulture Australia Project Number AP99010

National Application of New Techniques for Scald Control

Final Report

Project Leader:

Robert Holmes

Institute for Horticultural Development, Knoxfield,
Department of Primary Industries, Victoria.
Private Bag 15
Ferntree Gully Delivery Centre
Vic. 3156
Phone: 03 9210 9222
Fax: 03 9800 3521
E-mail: Robert.Holmes@nre.vic.gov.au

Other key personnel were:

Simone Kreidl, Scientist
John Lopresti, Scientist
Ian Wilkinson, Scientist
Christine Frisina, Technical officer
John Faragher, Scientist
Peter Franz, Biometrician
Fiona Thomson, Biometrician
Michael Rettke (SARDI)
Louise Chvyl (SARDI)
Ron Gordon (Batlow Fruit Co-op)
Gordon Brown (Scientific Horticulture Pty Ltd)
Kevin Scott (UNSW)

Purpose:
1. To investigate alternatives to DPA for the management of superficial scald in apples and pears.
2. Develop scald forecasting models for several cultivars and growing areas.
3. To reduce the need for DPA and fungicides, increasing marketability and minimising the problem of drench disposal.

The project was funded by the Apple and Pear Industry R&D levy, Horticulture Australia and the Department of Primary Industries, Victoria. Rohm and Haas supplied a voluntary contribution during 2001/02. Collaborating institutes were the South Australian Research and Development Institute (SARDI).

March 2003
Disclaimers:

Any recommendations contained in this publication do not necessarily represent current Horticulture Australia policy. No person should act on the basis of the contents of this publication, whether as to matters of fact or opinion or other content, without first obtaining specific, independent professional advice in respect of the matters set out in this publication.

The advice provided in this publication is intended as a source of information only. Always read the label before using any of the products mentioned. The authors, The State of Victoria and its employees do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaim all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.
# Table of Contents

1. Media Summary ........................................................................................................ 4

2. Technical Summary .................................................................................................. 5

3. Introduction ............................................................................................................... 6

   3.1 ScalD Forecasting ................................................................................................. 6
   3.2 Ultra Low Oxygen ............................................................................................... 7
   3.3 Alcohol Vapour .................................................................................................. 7
   3.4 1-Methylcyclopropene ...................................................................................... 8
   3.5 Canola Oil .......................................................................................................... 8
   3.6 Aims .................................................................................................................... 9

4. General Materials & Methods .................................................................................. 10

   4.1 Fruit Quality Measurements ............................................................................. 10
      4.1.1 ScalD Incidence and Severity ...................................................................... 10
      4.1.2 Maturity ..................................................................................................... 10
      4.1.3 Firmness ..................................................................................................... 10
      4.1.4 Colour ....................................................................................................... 10
      4.1.5 Total Soluble Solids ................................................................................. 10
      4.1.6 Internal Browning ..................................................................................... 10
   4.2 Controlled Atmosphere Storage Systems ......................................................... 11

5. ScalD Forecasting .................................................................................................... 12

   5.1 Introduction ....................................................................................................... 12
   5.2 Materials and Methods ..................................................................................... 14
      5.2.1 Cultivar, site selection and harvest .............................................................. 14
      5.2.2 Fruit quality measurement, CA storage and fruit assessment.................... 15
      5.2.3 Meteorological data and cumulative preharvest hours .............................. 15
      5.2.4 Experimental design .................................................................................. 16
      5.2.5 Statistical analyses and predictive model development ............................ 16
   5.3 Results ............................................................................................................... 18
      5.3.1 Granny Smith ............................................................................................. 20
      5.3.2 Pink Lady .................................................................................................. 25
      5.3.3 Red Delicious ............................................................................................ 34
      5.3.4 Fuji ........................................................................................................... 44
      5.3.5 Jonagold .................................................................................................... 46
      5.3.6 Gala .......................................................................................................... 48
   5.4 Discussion .......................................................................................................... 49

6. Ultra Low Oxygen .................................................................................................. 53

   6.1 Introduction ....................................................................................................... 53
   6.2 Materials and Methods ..................................................................................... 53
      6.2.1 Cultivar and Growing Region .................................................................... 53
      6.2.2 Experimental design .................................................................................. 53
      6.2.3 Statistical Analysis .................................................................................... 54
   6.3 Results ............................................................................................................... 54
      6.3.1 Red Delicious from Batlow ....................................................................... 54
      6.3.2 Red Delicious from Huonville ................................................................... 56
      6.3.3 Red Delicious apples from Victoria ............................................................. 58
      6.3.4 Pink Lady apples from the Yarra Valley ..................................................... 59
   6.4 Discussion .......................................................................................................... 60
7. 1-METHYLCYCLOPROPENE ................................................................. 61

7.1 INTRODUCTION .............................................................................. 61

7.2 EFFECT OF 1-MCP ON GRANNY SMITH APPLES - 2001 SEASON .......... 62

SUMMARY ....................................................................................... 66

INTRODUCTION ............................................................................. 67

2. MATERIALS AND METHODS ......................................................... 67

3. RESULTS ....................................................................................... 70

4. DISCUSSION AND CONCLUSIONS ............................................. 71

5. RECOMMENDATIONS ................................................................. 72

6. REFERENCES ............................................................................... 72

7. TABLES .......................................................................................... 73

8. PLATES .......................................................................................... 75

7.3 EFFECT OF 1-MCP ON GRANNY SMITH APPLES - 2002 SEASON ........... 77

SUMMARY ....................................................................................... 81

INTRODUCTION ............................................................................. 82

2. MATERIALS AND METHODS ......................................................... 82

3. RESULTS ....................................................................................... 86

4. DISCUSSION AND CONCLUSIONS ............................................. 88

5. RECOMMENDATIONS ................................................................. 89

6. REFERENCES ............................................................................... 89

7. TABLES .......................................................................................... 90

7.4 EFFECT OF 1-MCP ON RED DELICIOUS APPLES - 2002 SEASON .......... 99

7.4.1 Materials and Methods ............................................................. 99

7.4.2 Results ..................................................................................... 99

7.5 DISCUSSION ............................................................................... 100

8. ALCOHOL VAPOUR ................................................................. 101

8.1 INTRODUCTION .............................................................................. 101

8.2 ETHANOL — COOLSTORE TRIALS ............................................. 102

8.2.1 Materials and Methods ............................................................. 102

8.2.2 Results ..................................................................................... 102

8.3 PROPAN-1-OL — COOLSTORE TRIALS ........................................ 106

8.3.1 Materials and Methods ............................................................. 106

8.3.2 Results ..................................................................................... 106

8.4 PROPAN-2-OL (ISO-PROPANOL) — COOLSTORE TRIALS .......... 109

8.4.1 Materials and Methods ............................................................. 109

8.4.2 Results ..................................................................................... 109

8.5 COMBINATIONS OF ETHANOL AND PROPAN-1-OL ......................... 111

8.5.1 Materials and Methods ............................................................. 111

8.5.2 Results ..................................................................................... 111

8.6 DELAYED APPLICATION OF PROPAN-2-OL ..................................... 113

8.6.1 Materials and Methods ............................................................. 113

8.6.2 Results ..................................................................................... 113

8.7 DISCUSSION ............................................................................... 115

9. CANOLA OIL ................................................................. 116

9.1 INTRODUCTION .............................................................................. 116

9.2 COMBINATION OIL AND CA - 2000 SEASON .................................... 117

9.2.1 Materials and Methods ............................................................. 117

9.2.2 Results ..................................................................................... 117

9.3 ALTERNATIVE TREATMENTS - 2000 SEASON .................................... 120

9.3.1 Materials and Methods ............................................................. 120

9.3.2 Results ..................................................................................... 120

9.4 ORGANIC FRUIT - 2001 SEASON ................................................... 121

9.4.1 Materials and Methods ............................................................. 121

9.4.2 Results ..................................................................................... 121
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>PEARS - 2001 Season</td>
<td>124</td>
</tr>
<tr>
<td></td>
<td>9.5.1 Materials and Methods</td>
<td>124</td>
</tr>
<tr>
<td></td>
<td>9.5.2 Results</td>
<td>124</td>
</tr>
<tr>
<td>9.6</td>
<td>STRIPPED OIL - 2001 Season</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>9.6.1 Materials and Methods</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>9.6.2 Results</td>
<td>128</td>
</tr>
<tr>
<td>9.7</td>
<td>DISCUSSION</td>
<td>129</td>
</tr>
<tr>
<td>10</td>
<td>CONCLUSION</td>
<td>130</td>
</tr>
<tr>
<td>11</td>
<td>TECHNOLOGY TRANSFER</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>11.1 Publications</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>11.2 MEETINGS AND PRESENTATIONS</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>11.3 IMPLEMENTATION</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td>11.4 FURTHER RESEARCH</td>
<td>131</td>
</tr>
<tr>
<td>12</td>
<td>RECOMMENDATIONS</td>
<td>132</td>
</tr>
<tr>
<td>13</td>
<td>ACKNOWLEDGMENTS</td>
<td>134</td>
</tr>
<tr>
<td>14</td>
<td>BIBLIOGRAPHY</td>
<td>135</td>
</tr>
</tbody>
</table>
1. MEDIA SUMMARY

As a result of this project, growers and packers have new scald management tools to enable the reduction and elimination of postharvest chemicals. We have developed scald forecasting models based on harvest maturity and preharvest field temperature which estimate when fruit are likely to develop scald. What this means is that when the scald risk is low, fruit can be left undipped. When the risk is moderate, fruit can be treated with low rates of DPA or alternative scald controls such as ultra low oxygen storage or a more acceptable chemical option. Only fruit of high scald risk, which usually means they are intended for long-term storage in conventional CA, would need the full rate of DPA. There is now potential to export several varieties, within 6 months of harvest, without postharvest chemical treatment.

Superficial scald is a serious disorder of apples and pears. Occurring during cold storage it results in a brown discolouration making the fruit unmarketable and limiting its storage and export potential. Currently, scald is controlled by drenching with the antioxidant diphenylamine (DPA). However some markets no longer accept fruit treated with this chemical and there are increasing concerns about high residues and the disposal of used drench. Also, fruit may be being treated unnecessarily and this could be avoided if we could confidently predict that scald would not occur.

Scald forecasting models have been developed for Granny Smith grown in the Yarra Valley and Adelaide Hills, Red Delicious grown at Batlow and Huonville and Pink Lady from the Yarra Valley, Goulburn Valley, Adelaide Hills and Huonville.

Ultra low oxygen storage has been very successful in delaying the onset and reducing the severity of scald in Red Delicious and Pink Lady apples. In most cases ULO stored apples were virtually scald free for 6 months.

1-MCP (1-methylcyclopropene) is an ethylene action inhibitor, recently registered for apples and pears in the United States. In our evaluations, Granny Smith and Red Delicious apples remained scald free for 11 and 9 months respectively.

Fumigation with alcohol vapour or dipping in an emulsion of canola oil have limited applications.
2. TECHNICAL SUMMARY

Superficial scald is a serious physiological disorder of apples and pears. Occurring during storage it results in a brown discolouration making the fruit unmarketable and limiting its storage and export potential. It is thought to be due to the oxidation of α-farnesene and the build up of its oxidation products, conjugated trienes, which accumulate in the skin causing cellular damage and discoloration.

Currently, scald is controlled very effectively by postharvest drenching with the antioxidant diphenylamine (DPA). Almost all apples and pears grown in Australia are treated with DPA. However, some markets eg: apples to Japan, and pears to a number of Asian and European markets no longer accept fruit treated with this chemical. There are increasing concerns over residues that exceed the maximum residue limit. Also, the inability to predict scald occurrence results in fruit being treated unnecessarily. Drenching is wasteful and potentially polluting as the chemical mix needs to be discarded, and appropriate disposal methods may not be available in all situations. Drenching also disperses fungal inoculum making it necessary to use one or more fungicides. In addition, the consumers preference for “clean and green”, chemical-free produce makes alternatives to DPA desirable.

The aim of this project was to develop and evaluate several alternative methods of avoiding scald, including scald forecasting models, ultra low oxygen (ULO) storage, fumigation with 1-methylcyclopropene (1-MCP) and alcohol vapour and drenching in emulsified canola oil.

Models were developed that predict the first occurrence of scald based on harvest maturity (starch index), hours below 10°C in the orchard prior to harvest and the intended storage length. Each of these factors is highly correlated with scald susceptibility, however the importance of each factor in the models varies between cultivars and growing regions. Scald forecasting models have been developed for several cultivars and growing areas including Granny Smith from the Yarra Valley and Adelaide Hills, Red Delicious from Batlow and Huonville and Pink Lady from the Yarra Valley, Goulburn Valley, Adelaide Hills and Huonville.

Ultra low oxygen storage (1.1% O₂: 0.5% CO₂) successfully delayed the onset and reduced the severity of scald in Red Delicious and Pink Lady apples. In most cases, ULO stored apples were virtually scald free for 6 months whereas conventionally stored fruit (2.5% O₂: 1% CO₂) had significant amounts of scald at that time. After 9 months ULO storage, fruit began to develop a low incidence of scald. There were no detrimental effects observed on Red Delicious, but, in one season Pink Lady developed some slight alcoholic flavours under ULO.

The ethylene action inhibitor 1-MCP (1-methylcyclopropene) has recently been registered for use on apples and pears in the United States. In our evaluations, Granny Smith and Red Delicious apples of various harvest maturities remained scald free for 11 and 9 months respectively. Fruit were also firmer and greener with improved storage potential.

Ethanol and propanol vapours gave good scald control on Packham’s pears, Granny Smith and Pink Lady apples. However, there were problems with flavour tainting at the higher concentrations, while lower levels did not provide as effective scald control. Additional work would need to be done to determine effective treatment rates that do not affect flavour.

Dipping in a 1% emulsion of canola oil gave some reduction in the amount and severity of scald on Granny Smith and Red Delicious apples and Packham’s Triumph and WBC pears, but not enough to be useful commercially. When used on pears it aided in retaining firmness and greenness of some fruit. It could be useful for organic fruit to prolong storage life in the short term.

Growers wishing to reduce or eliminate DPA use have a number of treatment options available to them which can be used alone, in combination, or with reduced rates of DPA. The forecasting models can be a useful tool for choosing the type of treatment needed for efficient scald control. Eliminating the dipping process by using ULO, 1-MCP or alcohol vapour means that fungicide application may be avoided. These treatments will lead to a reduction in postharvest chemical residues, increased marketability and in some cases reduced costs.
3. INTRODUCTION

Superficial scald is a serious physiological disorder affecting many varieties of apples and pears. Occurring during storage it results in a brown discolouration making the fruit unmarketable and limiting its storage and export potential.

The exact mechanism of scald development is unclear but it is widely thought to be due to the oxidation of α-farnesene in the fruit skin. Alpha-farnesene is a naturally occurring compound produced by the fruit during ripening and storage. Its oxidation products are conjugated trienes, which accumulate in the skin and are believed to cause cellular damage. The brown discolouration, caused by oxidised phenols in the cell, is the final result of a series of oxidation reactions.

Currently scald is controlled very effectively by postharvest drenching with the antioxidants diphenylamine (DPA) and ethoxyquin. These chemicals are believed to prevent the oxidation of α-farnesene (Barlow 1988). DPA is the most widely used, although ethoxyquin is sometimes used on pears. Almost all apples and pears grown in Australia are treated with between 500 and 3,600 ppm of DPA regardless of the likelihood of scald development. However DPA treated fruit is not accepted by some markets such as apples to Japan or pears to a number of Asian and European markets, and its continued use is threatened by toxicological and environmental concerns.

DPA concentrations required for proper control of scald vary depending on variety and storage conditions. Commercially however, many cultivars are dipped with DPA at the same rate regardless of susceptibility. Such practice is more convenient than mixing up different concentrations for each apple type. Fruit are also sometimes found to have unacceptably high residue levels. Using lower concentrations of DPA would prevent high residues remaining on the fruit and the possibility of phytotoxic injury on treated apples and pears.

DPA application by immersion or drenching itself causes problems because the recirculated liquid disperses fungal inoculum, thereby increasing the risk of rots and making it necessary to apply a fungicide.

The drenching procedure is wasteful and potentially polluting because about one-third of the chemical mix needs to be discarded, and safe, sustainable disposal methods may not be available in all situations. In some cases DPA waste has to be transported long distances, at great cost, to be disposed of legally.

In addition the current consumer trend toward “clean and green” chemical free produce makes investigating alternatives to DPA desirable.

Alternative means of managing superficial scald are important for maintaining export and domestic markets for Australian pome fruit. The aim of this project was to investigate several alternatives to DPA for the control of superficial scald. These methods are mostly non-chemical, or low-chemical use, and include scald forecasting, canola oil dipping, alcohol fumigation, 1-MCP fumigation and ultra-low oxygen (ULO) storage.

As a result of this project it is expected that growers will have the choice of a variety of treatments depending upon the market, desired storage length and scald susceptibility. With a forecasting model to predict the likelihood of scald occurring, some fruit could be left completely untreated. Susceptible fruit could be treated with a combination of alternative methods including reduced rates of DPA if necessary.

3.1 Scald Forecasting

The key to successfully treating scald and minimising DPA use is knowledge of the scald susceptibility of the fruit at harvest. Susceptibility of fruit to superficial scald is influenced by many parameters including cultivar, pre-harvest temperatures and nutrition, maturity at harvest, storage length and storage conditions such as controlled atmosphere, temperature and humidity (Little and Holmes 2000).

The most important factors affecting scald development were found in most cases to be harvest maturity, pre-harvest hours below 10°C and storage length. These three factors form the basis of the predictive models developed in this study.
Wilkinson & Fidler (1973) determined that scald is more severe on a crop harvested after a warm, dry summer than on one grown during a dull, wet summer. Temperature, hours of sunshine and rainfall were factors suggested to be operative. Uota (1952) found that for McIntosh apples, scald incidence was positively correlated with air temperature during the last 24 days of the growing season. A preharvest temperature of 10°C was considered a threshold closely related to the incidence of scald in work conducted by Merritt et al. (1961) and Blanpied et al. (1991), who found that as pre-harvest hours below 10°C increased the levels of scald developing decreased.

Scald susceptibility is closely linked to harvest maturity (Wilkinson & Fidler, 1973; Anet, 1972). In general, fruit picked more mature is less susceptible to scald than immature fruit. Advanced maturity and low temperatures prior to harvest reduce the susceptibility of fruit to superficial scald (Bramlage & Watkins, 1994).

Storage time also influences the incidence and severity of scald. Fruit stored for longer than six weeks, the minimum time required for packaging and distribution to export markets, is likely to develop more serious scald disorders than fruit stored for less than six weeks (Barlow, 1988).

The data collected in this project build on the results of earlier trials (AP440) where two years data were collected for Granny Smith, Red Delicious and Pink Lady apples from the Yarra and Goulburn Valleys. Extra seasons of data were required to build accurate models for several cultivars and growing areas throughout the Australia.

3.2 Ultra Low Oxygen

Controlled atmosphere storage, particularly at very low oxygen levels in well ventilated stores, has proven to be an effective method of scald control (Little et al., 1991).

Lau (1985) compared rapid CA with ULO and conventional CA and found that Delicious and Golden Delicious apples developed less superficial scald in the ULO treatment. Recent evidence showed that ULO storage at oxygen levels below 1% can give complete scald control for up to 4 months on Granny Smith apples (Ghahramani and Scott 1998; Zanella 2003) and up to 8 months on Red Delicious (Wang and Dilley 2000). Initial low oxygen stress, where apples were stored at very low oxygen levels (0.25-0.5%) for several weeks before returning to conventional CA, has also been shown to be effective (Little et al. 1982, Wang and Dilley 2001). There are concerns that the risk of low oxygen injury may be too great to make this a practical treatment, and further work has been recommended in this area.

Superficial scald is thought to be caused by the oxidation of $\alpha$-farnesene to conjugated trienes in the fruit skin. The rate of this reaction is determined by the concentration of oxygen in the storage atmosphere. Therefore, lower oxygen levels are less conducive to scald development. Wang and Dilley (2001) showed that $\alpha$-farnesene production decreased as oxygen levels declined, and the production of MHO (6-methyl-5-hepten-one), one of the products of $\alpha$-farnesene breakdown, was completely arrested by oxygen levels below 1.25%.

It has also been proposed that ethanol and other volatiles produced by the fruit at low oxygen levels contribute to scald control, although the mode of action is not known. Ghahramani and Scott (1998) and Wang and Dilley (2001) suggested that the beneficial effect of low oxygen treatments may be due to the ethanol produced under these conditions.

3.3 Alcohol Vapour

Alcohol vapour has been shown in several instances to be an effective control against superficial scald. It acts by reducing the production of $\alpha$-farnesene and preventing its breakdown to conjugated trienes (Ghahramani and Scott 1998, Ghahramani et al. 1999). Ritenour et al. (1997) found that ethanol reduced the production of ethylene in avocado and honeydew melons. As ethylene is involved in regulating $\alpha$-farnesene production, this may indicate how ethanol affects scald development.

Scott et al. (1995) showed that 0.5 to 1g of ethanol per fruit completely controlled scald on Granny Smith apples. Ghahramani et al. (2000) demonstrated that other alcohols, 1-propanol and 1-butanol, are also effective scald inhibitors.
Alcohol vapour treatment could work well in combination with controlled atmosphere treatments. The combination of ethanol vapour and CA storage has greater effects on scald reduction than either of these two treatments alone (Chervin et al. 2001). It has also been suggested that natural production of ethanol during low oxygen storage may be partially responsible for its effect on scald control (Ghahramani and Scott 1998, Wang and Dilley 2001).

### 3.4 1-Methylcyclopropene

1-Methylcyclopropene (1-MCP) is an ethylene action inhibitor that has been studied for some time in relation to storage life of cut flowers (Sisler and Serek 1997). It has been shown to improve the storage potential of ethylene sensitive produce such as apples (Fan et al. 1999), bananas (Jiang et al. 1999), and broccoli (Ku and Wills 1999). It acts by permanently binding to the ethylene receptors (Sisler and Serek 1997). Any ethylene mediated reactions are temporarily disrupted until new receptor sites are manufactured.

Very low concentrations of 1-MCP have been shown to provide excellent control of superficial scald. There are correlations between increasing internal ethylene and \(\alpha\)-farnesene production (Ju and Curry 2000). As well as inhibiting ethylene action, 1-MCP is reported to delay or reduce the accumulation of \(\alpha\)-farnesene and its oxidation products (Watkins et al. 2000), therefore delaying scald development.

The dose of 1-MCP needed to effectively prolong storage life in apples is dependent upon cultivar and storage conditions (Watkins et al. 2000) and in some cases has resulted in failure of pears to ripen normally (Ian Wilkinson pers.com.). These points need to be taken into consideration when treating apples and pears for scald control.

Lurie et al. (2002) reported that Anna apples treated with 1µl /L 1-MCP developed less ripe aromas than control fruit or fruit treated with 0.1µl /L 1-MCP, although the consumer preference was for the fruit treated with the higher concentration.

1-MCP has recently been registered for use on apples and pears in the United States and registration in Australia is expected within the next few years. 1-MCP is attractive because it can be applied at very low concentrations (less than 1ppm), is easy to apply as a fumigant, avoids dipping and is easy to dispose of. According to the manufacturers, Rohm and Haas, there are no detectable residues. It provides very reliable and long term scald control. This study looks at its effectiveness on Granny Smith and Red Delicious apples.

### 3.5 Canola Oil

For several decades some degree of scald control was obtained commercially by wrapping fruit in paper containing 15% mineral oil (Scott et al. 1995) or by distributing oil impregnated strips of paper throughout the apple cartons or bins (Ingle and D’Souza 1989). However, scald control under these conditions was not perfect and more effective means such as DPA were adopted.

Recently Scott et al. (1995) found that several vegetable oils, when applied to the fruit by hand, considerably reduced the amount of scald developing on Granny Smith apples. However this application process is time consuming and would not be practical commercially.

Ju et al. (2000) showed that plant oil emulsions applied as a dip were effective in reducing the occurrence of scald. They also found that several plant oils delayed ethylene production and helped maintain the firmness and greenness of Chinese pears.

The oils may act by removing volatile substances from the fruit surface. Oiled wraps were found to absorb \(\alpha\)-farnesene thus removing it and its oxidation products from the fruit (Huelin and Coggioila 1968). It is also possible that they function as a physical barrier causing modification of the fruits’ internal atmosphere.

Canola oil is a natural product that is environmentally friendly and widely available in Australia. Its use would be acceptable in both conventional and organic markets.
3.6 Aims
The original aims of this project were —
1. To confirm the applicability of vegetable oil and ethanol treatments to varieties other than Granny Smith.
2. To refine application methods for both substances.
3. To collect information required by the regulatory authorities to permit the use of these substances.
4. To finalise the scald forecasting model for Red Delicious, develop models for other varieties and confirm their applicability in states other than Victoria.
5. To determine the low oxygen tolerance of Red Delicious from several localities to evaluate the potential for using low oxygen stress for scald control.

In addition to this, trials investigating the use of 1-MCP were added to the project in 2001-02 and ethanol treatments were expanded to include the use of propanol.

Outcomes from the project include —
1. Identifying and describing the best scald control options for popular varieties.
2. Reducing the need for DPA and fungicides minimising the problem of drench disposal.
3. Obtaining data required for the registration/approval of oil and ethanol treatments.
4. Better retention of green colour and firmness in Packham’s Triumph and WBC pears.
5. Storage of oil-treated apples at moderate oxygen levels, instead of low oxygen, thus substantially lowering costs.

The anticipated long term outcome for industry is enhanced marketability and market access for apples and pears.
4. GENERAL MATERIALS & METHODS

4.1 Fruit Quality Measurements

4.1.1 Scald Incidence and Severity

In most cases fruit was assessed only for incidence of scald. Any scald regardless of the intensity of browning or percentage of fruit skin covered was recorded and the percentage of fruit affected calculated.

In Red Delicious apples there was a percentage of fruit developing a brown skin discoloration that was not superficial scald. This browning generally occurred on the green side of the fruit and lacked the characteristic irregular appearance of scald. This was assessed as ‘discolouration’. In some cases it was difficult to distinguish from mild scald in which case results are presented as ‘scald’ and ‘scald + discolouration’.

4.1.2 Maturity

Fruit maturity was assessed using the starch iodine test, which measures the distribution of starch in the fruit, and the extent to which starch has been converted to sugars. At each harvest twenty fruit were picked at shoulder height from a representative sample of trees. Apples were assessed as soon as possible after picking using a 1-5 (6 point) starch index scale, where 1 = no starch conversion in the apple interior, and 5 = no starch left in the apple interior. Patterns were compared using a concentric type rating scale for Red Delicious and Fuji cultivars while a radial type scale was used for Gala, Jonagold, Pink Lady and Granny Smith varieties.

4.1.3 Firmness

Fruit was assessed for firmness on one side of the fruit (chosen at random) using a hand-held Effegi penetrometer. A strip of skin was removed with a vegetable peeler from the cheek of the fruit, midway between the stem and calyx, and the plunger inserted up to the scribed line. The plunger diameter was 8 mm for pears and 11 mm for apples. Results were recorded in kg force and the mean of several apples was calculated.

4.1.4 Colour

Colour was measured with a Minolta CR-200 Chromameter (Minolta, Osaka, Japan) using the white calibration tile and a C illuminant (6774 k). Hue angle (H°) was calculated from the L,a and b measurements using the equation \( H° = \arctan(b/a) \) where \( 0° = \text{red}, 90° = \text{yellow} \) and \( 180° = \text{green} \). Colour was not generally measured on Red Delicious apples as no change in the green background colour, indicating ripening or maturity in other cultivars, was visible.

4.1.5 Total Soluble Solids

TSS (total soluble solids) were measured using a KRÜSS model DR 10/32 digital refractometer. Individual fruit were measured, using the juice expressed while conducting firmness tests, and the mean calculated.

4.1.6 Internal Browning

Incidence of internal browning was visually assessed on a sub-sample of fruit.
4.2 Controlled atmosphere storage systems

Fruit was stored either in individual controlled atmosphere tubs, or in larger bulk storage tents for the forecasting trial. Tubs were 150 L with a steel base and an airtight perspex lid with water seal. Tents were approximately 4500 L made of heavy plastic with a ‘zip lock’ seal. Both tubs and tents were connected to a flow-through nitrogen purging system. Atmospheres were controlled by an Oxystat 2002 controller (David Bishop Instruments, Heathfield, East Sussex, England) equipped with a Servomex paramagnetic O₂ analyser and an infra-red CO₂ analyser.
5. SCALD FORECASTING

5.1 Introduction

Prediction of scald susceptibility of fruit at harvest is an important component of any alternative approach to scald control aiming to reduce or eliminate DPA use. Susceptibility of apples to scald varies greatly with cultivar, orchard location, harvest maturity, storage conditions and season (Wilkinson & Fidler, 1973; Emongor et al., 1994). Previous studies have demonstrated that environmental factors such as ambient air temperature, relative humidity and light intensity, as well as fruit maturity may be used as reliable indicators of scald susceptibility (Curry & Weis, 1996).

In general, apples that mature in warmer drier environments that are likely to be more prone to water stress, appear to have a higher susceptibility to superficial scald (Wilkinson & Fidler, 1973; Anet, 1972). Uota (1952) found that for McIntosh apples, scald incidence was positively correlated with air temperature during the last 24 days of the growing season. As ambient temperature strongly affects the vapour pressure deficit between the apple and its environment, it is likely that these correlations between scald and temperature have a strong relationship to water stress in the apple as well. In observations made by Little & Holmes (2000), hot, dry and sunny growing conditions produce fruit with higher susceptibility to superficial scald, particularly if such conditions are endured close to harvest.

Scald susceptibility is closely linked to harvest maturity (Wilkinson & Fidler, 1973; Anet, 1972). Fruit picked more mature is less susceptible to scald than immature fruit. Maximum susceptibility to superficial scald coincides with a stage of maturity that exists ten to fifteen days before the start of an increase in the core ethylene concentration, the pre-climacteric stage of ripeness (Little & Holmes, 2000). Bramlage & Watkins (1994) found that advanced maturity at harvest consistently reduced the incidence of superficial scald in New Zealand apple growing districts. The dilemma is that fruit picked at an advanced maturity generally has a shorter storage life due to a higher susceptibility to internal breakdown. It has been difficult to determine whether temperature prior to harvest is more closely related to scald development than maturity because the two are partially confounded. Correlation of reduced scald potential with temperature can be difficult as fruit maturity in most cultivars increases with the occurrence of cooler days and nights (Curry & Weis, 1996).

It has been suggested that superficial scald is a form of ‘chilling’ injury whereby low ambient temperatures beginning 30 to 40 days before harvest preconditions fruit for cold temperatures during storage thereby decreasing the susceptibility of fruit to scald. It is this reasoning that has lead to researchers’ attempts to develop predictive models for scald using accumulated hours below a threshold temperature prior to harvest. A preharvest temperature of 10°C was considered a threshold closely related to the incidence of scald in work conducted by Merrit et al., (1961), Gorini (1965), and Blanpied et al., (1991). However, Morris (1964) found that 13°C is a more accurate temperature for scald prediction. Curry (1990) found that the relationship between accumulated hours and scald incidence in Washington State was very similar when using a threshold temperature of 7, 10 or 13°C.

Merrit et al., (1961) examined the relationship between air temperature and occurrence of scald out of storage for ‘Stayman’ apples in the U.S. They found a significant reduction in scald susceptibility with an accumulation of more than 150 hours at less than 10°C and practically scald-free fruit when 190 or more hours had been accumulated. This relationship was confirmed by Bramlage and Barden (1989) for ‘McIntosh’, ‘Cortland’ and ‘Delicious’ apples also in the U.S. They found that 100 hours below 10°C were necessary for substantial scald resistance in ‘Cortland’, whereas for ‘McIntosh’ higher hours were needed. They were unable to determine the number of hours required before scald resistance became apparent in ‘Delicious’ due to the large number of hours below 10°C that all samples experienced before harvest.

Results obtained from predictive models based on accumulated hours in New Zealand have so far been inconsistent. Bramlage & Watkins (1994) found that accumulated hours below 10°C was not a generally applicable scald predictor for New Zealand climatic conditions, despite the fact
that a similar model reliably predicted scald incidence under U.S. conditions. The predictive value was not improved by combining the variables: harvest date, starch scores and cumulative hours below 10°C. They further concluded that neither starch score at harvest nor calendar date are likely to be satisfactory scald predictors, and that the use of a higher threshold temperature may be needed for a more broadly applicable scald index.

Little and Barrand (1989) observed that when hot seasons and milder seasons are compared, maximum temperature rather than the average of the maximum and minimum temperature between December and April is more useful in determining scald correlations in Australia.

The difficulty of developing a broadly applicable predictive model for scald based on a single factor such as cumulative preharvest hours is apparent particularly when considering the variability of scald susceptibility between seasons, harvests within seasons, and growing areas (Wilkinson & Fidler, 1973). This is further complicated by the potential effect of tree vigour, fruit nutrient content, fruit size, soil moisture and irrigation regime on scald incidence (Kupferman, 2001). Weather patterns will also vary slightly each season and this will influence the rate of fruit maturation. Therefore, scald prediction models are likely to be best developed with both a weather component and one related to fruit maturity (Curry & Weis, 1996).

The aim of this scald forecasting work was to study the relative scald susceptibility of various apple cultivars grown in different Australian districts and model the relationship between scald incidence and ambient temperature, fruit maturity and storage time in CA. This study will look at the effect of factors that have not been considered in previous scald prediction work, such length of storage time and storage under CA conditions, to simulate commercial practice.
5.2 Materials and Methods

5.2.1 Cultivar, site selection and harvest

Seven pome fruit growing districts in Australia were included as part of this work between 1995 and 2002. Districts sampled, and numbers of orchards sampled in a district, varied among years and among cultivars. District and cultivar combinations used in trials are described in Table 1. The same orchards within a region were not always used each year. In each season fruit was harvested two or three times from mature trees at weekly intervals spanning the commercial harvest period for the cultivar studied. Trees used were at least 7 years old and producing a commercial harvest. Orchard sites used in trials were trickle irrigated and did not use overhead netting.

Table 5.1. Summary of district locations, characteristics, apple cultivars and harvest dates used in forecasting trials between 1995 and 2002.

<table>
<thead>
<tr>
<th>District</th>
<th>Orchard blocks used</th>
<th>Climatic characteristics</th>
<th>Elevation range (metres)</th>
<th>Cultivars studied</th>
<th>Harvest period</th>
<th>Years of data collection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yarra Valley, Vic.</td>
<td>3</td>
<td>Warm day, cool night, dry, sunny</td>
<td>100 - 200</td>
<td>Pink Lady</td>
<td>Late April</td>
<td>1997-1999, 2001-2002</td>
</tr>
<tr>
<td>Goulburn Valley, Vic.</td>
<td>2</td>
<td>Hot day, hot night, dry, sunny</td>
<td>50</td>
<td>Pink Lady</td>
<td>Late April</td>
<td>1997-2002</td>
</tr>
<tr>
<td>Batlow, NSW</td>
<td>1</td>
<td>Warm day, cool night, dry, sunny</td>
<td>600-800</td>
<td>Pink Lady</td>
<td>Late April</td>
<td>2000-2002</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td>Red Delicious</td>
<td>Mid-March</td>
<td>2000-2002</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>Gala</td>
<td>Early March</td>
<td>2000-2001</td>
</tr>
<tr>
<td>Adelaide Hills, SA</td>
<td>2</td>
<td>Moderate day, cool night</td>
<td>300</td>
<td>Granny Smith</td>
<td>Late April</td>
<td>2000-2002</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>Pink Lady</td>
<td>Late April</td>
<td>2000-2002</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>Red Delicious</td>
<td>Early March</td>
<td>2000</td>
</tr>
<tr>
<td>Hounville, Tas.</td>
<td>2</td>
<td>Warm day, cool night, dry, sunny</td>
<td>100</td>
<td>Red Delicious</td>
<td>March - April</td>
<td>2000-2002</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>Jonagold</td>
<td>Early April</td>
<td>2001-2002</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>Gala</td>
<td>Early March</td>
<td>2000-2001</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>Pink Lady</td>
<td>Late April</td>
<td>2000-2002</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>Fuji</td>
<td>Mid-April</td>
<td>2001-2002</td>
</tr>
<tr>
<td>Stanley, Vic.</td>
<td>1</td>
<td>Hot day, cool night, dry, sunny</td>
<td>300</td>
<td>Red Delicious</td>
<td>Late March</td>
<td>1997-1998, 2000</td>
</tr>
<tr>
<td>Mornington Peninsula,</td>
<td>1</td>
<td>Hot day, warm night, dry, sunny</td>
<td>100</td>
<td>Red Delicious</td>
<td>Early March</td>
<td>1997-1998</td>
</tr>
<tr>
<td>Vic.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
At each harvest date, apples were randomly picked from all compass quadrants of the canopy from uniform and adjacent trees within each orchard. Fruit displaying rot or other disorders were not collected. Either six or nine trees or groups of trees at each trial site were selected as replicated field blocks depending on the experimental design used. For the majority of trials the same block of trees in an orchard was used for each cultivar from one season to the next.

Ninety apples per tree were picked into 36 litre plastic crates at each harvest and randomly divided into three samples of 30 apples that were placed inside plastic onion bags. Each sample was assigned to one of three storage times. Fruit harvested from Victorian sites was road-transported in crates to the Institute for Horticultural Development in Melbourne and placed in conventional cool storage at 0-2°C on the same day. Harvested apples from interstate were packed into lined cartons and then road-transported to the research station within 2 days of picking for cooling and subsequent controlled atmosphere storage.

5.2.2 Fruit quality measurement, CA storage and fruit assessment

Within 12 hours of each harvest, flesh firmness (kg), starch-iodine index (1-5) and TSS (°Brix) was measured on 20 fruit randomly picked from each orchard block. Quality measurement procedures are described in detail in Section 4 of this report. Harvested fruit samples in labelled onion bags from each orchard and field block (tree) were randomly assigned to 36 litre plastic crates. Plastic crates were stacked in layers and sealed inside plastic storage tents with a volume of 3,350 litres. Where more than one harvest date was used, samples from different harvest dates were randomised within each layer. Fruit was stored at 0-1°C and greater than 85% RH in a 2.5% O₂ and 1% CO₂ atmosphere. Oxygen and CO₂ levels were measured and controlled using a David Bishop Oxystat 900 controller (David Bishop Instruments, Heathfield, East Sussex, England) equipped with a Servomex paramagnetic O₂ analyzer and a infra-red CO₂ analyzer. The system maintained O₂ and CO₂ concentrations to within 0.2% of the set point. CA atmospheres were established within 3 days of harvest. Storage times used in forecasting trials varied between 3 and 8 months depending on the cultivar selected.

After removal from storage, fruit was stored in air at 20°C and greater than 65% RH for 7 days and then visually evaluated for the presence or absence of scald. Apples with more than “slight” scald, ie. Greater than 0.5 cm² of scalded fruit area, were considered commercially unacceptable. In some instances presence of scald on Red Delicious apples was difficult to determine due to difficulties in distinguishing the disorder from discolouration of fruit. This is will be discussed further in the Results section of the report. Fruit was then cut radially and evaluated for the presence of internal breakdown. The incidence of superficial scald and/or internal breakdown was expressed as the percentage of fruits in the sample having more than slight scald symptoms. Air-stored fruit samples were used to monitor the progress of scald development.

5.2.3 Meteorological data and cumulative preharvest hours

Ambient air temperature, rainfall and relative humidity data for each district were obtained from various sources including Australian Bureau of Meteorology (BOM) weather stations, ‘CropWatch’ orchard chart recorders and Hobo™ temperature loggers (Hastings Data Loggers, Australia). Where used, two temperature loggers were installed in sheltered and shaded positions at a height of approximately 1.5 m within the orchard block and temperature and RH data collected from the 1st February through to harvest. Hourly temperature data was used to calculate accumulated hours below 8, 10 and 12°C and above 22, 25 and 30°C. For some late-picked cultivars such as Pink Lady accumulated preharvest hours were calculated from the 1st March to harvest. Individual orchard blocks within a district were always located within 10 kilometres of the weather station used to collect meteorological data. The effect of elevation differences between orchard blocks within a district was accounted for by ensuring that individual temperature loggers were installed in each orchard. At each site, harvest date, days from the 1st February to harvest, and total days where minimum air temperatures fell below 10°C and maximum temperatures rose above 25°C, were also recorded.
5.2.4 Experimental design

For a single site (orchard block) in each year, the experimental treatments consisted of two or three harvest dates and two, three, four or five removals. Usually there were three harvest dates and three storage periods. Three, six or nine replicates (blocks) were used for each removal-harvest combination. Where two sites in the same district were used each site contained three replicates. Each block was large enough to harvest the total number of fruit for one replicate of all harvest and storage times; it was usually one tree, with groups of trees used for lower yielding trees. Within each block, a total of six to nine samples of thirty fruit were picked at each of two or three harvest dates. At each harvest, the storage times were allocated to samples of 30 fruit and the samples from one harvest were placed in one crate.

For each year-site combination, the fruit were stored under CA according to a split-plot design. The three crates within each field block were the experimental units for the harvests; within each crate, the three bags of 30 fruit were the experimental units for the removals. Each treatment factor was randomly assigned to its experimental units. Where possible the same cultivar from different sites was stored in a single tent.

5.2.5 Statistical analyses and predictive model development

The aim of this scald forecasting work was to study the relative scald susceptibility of various apple cultivars grown in different Australian districts and model the relationship between scald incidence and ambient temperature, fruit maturity and storage time in CA. The variable to be predicted is the percentage of scalded fruit after CA storage. An analysis of residual versus fitted plots demonstrated that the angular transformed percentage of scalded fruit had to be used to better meet the normality and constant variance assumptions of the statistical analysis. It was also found that this transformation improved the model fit to the data.

For these preliminary models, the predictor variables were based on accumulated preharvest hours below 10°C, starch score at harvest and storage time. From previous work it was decided that each district and cultivar combination had to be modelled separately due to the variation in the levels of scald incidence and magnitude of preharvest factors between districts.

As there was more than one type of experimental unit in this design, linear mixed models were fitted by a REML analysis with a random structure of \( \text{year}.\text{site}/\text{block}/\text{crate}/\text{bag} \) using GenStat 5 (Rothamsted Experimental Station, Hertfordshire, UK). The fixed part of the model included both linear and quadratic terms of accumulated preharvest hours below 10°C, starch score and storage time. To examine whether the linear effects depended on each other, the terms of all pairs of linear by linear predictors were also added eg. Starch score \( \times \) Storage time. Significance of the fixed effects was determined at this preliminary stage using Wald statistics under an asymptotic approximation of the Chi-squared (\( \chi^2 \)) distribution.

The adequacy of the model fit to the data was also assessed by examining pair wise plots of angular transformed percentage of scalded fruit versus each predictor variable for predicted values and experimental data. Where a model has been fitted to percentage of scalded fruit for a cultivar and district combination, the coefficients of each fitted term for the proposed linear mixed model are detailed in the Results section. These include standard errors and significance of the Chi-squared probability for dropping individual terms from the full fixed model. The range of storage and maturity measurements within which scald data was obtained is also provided.

An analysis of variance (ANOVA) was performed on percentage of scalded fruit from cultivar and district combinations for which only two years of results are available. Fitting a prediction model to these limited data sets was considered inappropriate due to a lack of a sufficient number of preharvest hours and starch score values obtained during trials.

By determining the effect of storage period and harvest date on scald incidence on a year-by-year basis a better insight will be gained regarding the potential for development of a predictive model based on data from further trials.

The predictors and fixed models fitted in this analysis are a first attempt at obtaining a good predictive model. Further statistical analysis and fitting of different model predictors will be required to determine the best fitting models for each cultivar and district combination. Further
development of the models, including alternative additional predictors, is required in order to obtain suitable predictive models for each cultivar and district combination.
5.3 Results

The effects of weather, fruit maturity and storage time on superficial scald incidence have been studied for six apple cultivars across seven pome fruit districts as outlined in Table 1. Results obtained from the initial three-year study (1995-1998) demonstrated that the development of a general scald susceptibility model for each cultivar that could be used across districts was unlikely. This indicated that forecasting models would be required for each district-cultivar combination as specific factors influencing scald susceptibility varied between locations. It should be recognised that the many factors considered to influence scald incidence and severity are related to one another and that weather patterns in a district will determine the most important of these. The major aim of this work was to collect sufficient scald data over a number of years for each cultivar-district combination to be able to identify specific predictors of scald susceptibility. Growers and CA store operators could then use relationships based on these predictors to minimise DPA use on fruit determined to be of low scald susceptibility.

The focus of the trials over the last three years has been to determine the relationship and interaction between scald susceptibility and the predictors described in Table 5.2. Not all the predictors studied are listed and of those described not all were used in each forecasting model. The factors selected depended primarily on cultivar, district climate, harvest date and model fit to scald incidence data. For example, in warmer districts, apples generally did not experience many preharvest hours below 10°C near harvest so this factor could not be evaluated even though it may have been important for some cultivars. In many cases the interaction between different preharvest factors, as well as with storage time, was as important as the effect of individual predictors. Total soluble solids (TSS) and fruit firmness were determined to be poor predictors of scald susceptibility due to the large variation in these maturity measurements within and between harvests. This result occurred regardless of the cultivar studied or the districts from which apples were harvested and so these measurements have not been presented here.

Table 5.2. Description of preharvest measurements and storage factors used as predictors in scald susceptibility models.

<table>
<thead>
<tr>
<th>Factors used to predict scald susceptibility</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preharvest hours</td>
<td>Number of cumulative hours between 1st February to harvest during which apples are subjected to ambient temperatures above or below a ‘selected’ base temperature i.e. below 8°C, 10°C or 12°C or above 22°C or 25°C. The base temperature used will depend on the cultivar, harvest date and district climate. For some later varieties 1st March is used as the starting date.</td>
</tr>
<tr>
<td>Starch score</td>
<td>Fruit maturity at harvest as measured by a starch/iodine test using cultivar-specific starch plates and a 1-5 scale.</td>
</tr>
<tr>
<td>Storage time</td>
<td>Number days that fruit is stored in CA from harvest to removal.</td>
</tr>
<tr>
<td>Days from 1st February to harvest</td>
<td>A measure of fruit maturity as the number of days accumulated between 1st February and the harvest date. For some later varieties 1st March is used as the starting date.</td>
</tr>
</tbody>
</table>

The terminology above will be used in the following discussion regarding model development for specific cultivars and districts. An important consideration in selecting predictors was the ease and practicality with which growers could measure the required data for input into forecasting models.
In discussing scald incidence levels, a batch of fruit is considered highly susceptible to superficial scald if percentage incidence for a specific storage time, starch score and preharvest hour combination is greater than 60%. On the other hand, fruit with less than 20% scald incidence are considered of low susceptibility or scald-resistant while apples between these values are deemed to be of intermediate scald susceptibility (Weis et al., 2000). In this study, fruit is considered of low susceptibility or scald resistant if less than 5% of apples in a sample have scald symptoms as this is a more realistic limit for growers using forecasting.
5.3.1 Granny Smith  

Adelaide Hills, South Australia  

Scald incidence data generated for ‘Granny Smith’ apples harvested from two orchards in the Adelaide Hills in South Australia over three years shows that fruit maturity is an important predictor of ‘Granny Smith’ scald susceptibility in this district. Two orchards were used to provide a more representative sample of fruit from this district. A plot of mean scald incidence after three different storage periods against starch score at harvest for all years studied demonstrates that a relationship may exist between scald susceptibility, starch score and storage time (Figure 5.1). By focusing on each storage time separately a clearer picture of the relationship between scald and fruit maturity can be obtained although the data is variable.

![Figure 5.1](image)

**Figure 5.1.** Scald development in ‘Granny Smith’ apples picked from the Adelaide Hills in South Australia over three years when removed from storage after 4, 5 or 6 months in relation to starch score at harvest. Each point represents one year × harvest × removal combination.

In addition,  
- Starch score as represented by the linear term in the model was found to be a highly significant predictor of scald incidence in this district (Table 5.3) while storage time also had a small but significant effect on scald susceptibility.  
- The (Starch score)^2 term in the fitted model was also highly significant indicating a curvilinear relationship is likely to exist between fruit maturity and scald incidence for this cultivar in the Adelaide Hills.  
- Scald incidence data initially suggested that number of days from 1st February to harvest may be a more consistent predictor of scald susceptibility for ‘Granny Smith’ in this district but it was not found to be a significant predictor when the model was fitted.  
- The daily minimum temperature in this district doesn’t generally begin to fall below 10°C until mid-March resulting in relatively few accumulated preharvest hours compared to other districts at similar elevations.  
- Figure 1 suggests that ‘Granny Smith’ in this district remains susceptible to scald at relatively high starch scores and that for short-term storage of four months or less in CA, fruit will require a starch score of at least 4.0 at harvest to have some resistance to scald.

Further analysis of scald incidence data and predictor variables should enable the development of useful predictive models for ‘Granny Smith’ grown in this district.
Yarra Valley, Victoria

Accumulated preharvest hours below 10°C between 1st February and harvest, and storage period, were the most appropriate predictors of scald susceptibility for ‘Granny Smith’ apples harvested from two orchards in the Yarra Valley in Victoria, over four seasons between 1996 and 2001 (Table 5.3). A plot of mean scald incidence after 5 or 6 months storage for all years studied against accumulated preharvest hours below 10°C indicates that scald incidence decreases dramatically with increasing ‘cold’ temperatures before harvest (Figure 5.2).

![Figure 5.2. Effect of preharvest hours below 10°C on scald incidence in ‘Granny Smith’ apples harvested from the Yarra Valley in Victoria over four seasons when removed from storage after 5 or 6 months. Each point represents one year\times harvest \times removal combination.](image)

In addition,
- Minimum temperatures during late March and April in the Yarra Valley consistently remain below 10°C for up to 12 hours per day resulting in fruit harvested late being exposed to many accumulated preharvest hours.
- Fruit maturity at harvest as measured by a starch iodine test was not a significant predictor of scald incidence even though a relatively wide range of starch scores were recorded i.e. 2.5 to 4.0.
- The interaction between storage time and preharvest hours was also significant (at the 1% level) demonstrating that the effect of preharvest hours on scald incidence varies depending on the length of the storage period.
- The \((\text{hour}10)^2\) term in the model is highly significant indicating that the relationship between scald susceptibility and preharvest hours is likely to be of a curvilinear nature. This implies that scald susceptibility will fall relatively rapidly as preharvest hours increase.

Fruit accumulating more than approximately 400 preharvest hours below 10°C and stored for up to five months in CA are likely to have low scald susceptibility. Fruit exposed to greater than 500 preharvest hours have the potential to be stored in CA for six to seven months using very low or reduced DPA rates.

The wide range of preharvest hours recorded over four seasons should enable the future development of a robust model.
Goulburn Valley, Victoria

The most comprehensive data set for ‘Granny Smith’ apples has been obtained from the Goulburn Valley in Victoria. Scald incidence data collected over five years from two orchards indicates that starch score and preharvest hours below 10°C or 12°C are poor predictors of scald susceptibility in this warm district. A plot of mean scald incidence for all years studied against accumulated preharvest hours above 25°C suggests that a ‘warm’ temperature predictor may be appropriate for this district but also indicates that the year effect is important (Figure 5.3).

![Figure 5.3](image)

**Figure 5.3.** Scald development in ‘Granny Smith’ apples from the Goulburn Valley in Victoria over five seasons when removed from storage after 5 months in relation to accumulated preharvest hours above 25°C between February 15 and harvest. Each point represents one year × harvest × removal combination.

In addition,

- In three of the five years scald incidence in ‘Granny Smith’ harvested from this district was very high, that is, greater than 70% in fruit stored for 6 months or more regardless of the harvest date or maturity.
- Preharvest hours above 25°C is an important predictor of scald susceptibility as is storage time (Table 5.3). The significance of the quadratic term for both of these predictors indicates that a curvilinear relationship with scald incidence is likely.
- The plotted data suggests that year effects are important as scald incidence data for individual years is generally clustered together (Figure 5.3). This may be due to changes in orchard management practices or climatic conditions between years not recorded in the study.
- In several years late harvested fruit stored beyond 6 months had high rots and some samples developed ‘soft’ scald. These factors may have disguised the true scald levels in these samples.

At this stage indications are that fitting a reliable prediction model to scald incidence data for ‘Granny Smith’ apples from the Goulburn Valley may be difficult and that storage time and a ‘warm’ temperature factor are the likeliest potential scald susceptibility predictors in this district.
Table 5.3. Linear mixed model and data range used for fitting orchard temperature, maturity and storage time to the angular transformed percentage of scald incidence for ‘Granny Smith’ apples from three districts.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Yarra Valley</th>
<th></th>
<th></th>
<th>Adelaide Hills</th>
<th></th>
<th></th>
<th>Goulburn Valley</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed model</td>
<td>Chi-squared</td>
<td>Fixed model</td>
<td>Chi-squared</td>
<td>Fixed model</td>
<td>Chi-squared</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>coefficients</td>
<td>prob</td>
<td>coefficients</td>
<td>prob</td>
<td>coefficients</td>
<td>prob</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>Constant</td>
<td>-54.1</td>
<td>88.1</td>
<td>110</td>
<td>82.7</td>
<td>-273</td>
<td>44.9</td>
<td>1.67</td>
<td>0.174</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Storage time</td>
<td>0.689</td>
<td>0.276</td>
<td>1.53</td>
<td>0.605</td>
<td>1.67</td>
<td>0.174</td>
<td>0.00316</td>
<td>0.000498</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>(Storage time)^2</td>
<td>-0.000449</td>
<td>0.000542</td>
<td>-0.00250</td>
<td>0.00201</td>
<td>-0.00316</td>
<td>0.000498</td>
<td>4.79</td>
<td>3.61</td>
<td>0.184</td>
</tr>
<tr>
<td>Starch score</td>
<td>51.7</td>
<td>43.8</td>
<td>-69.0</td>
<td>22.6</td>
<td>4.79</td>
<td>3.61</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
</tr>
<tr>
<td>(Starch score)^2</td>
<td>-10.4</td>
<td>5.90</td>
<td>10.4</td>
<td>4.00</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
</tr>
<tr>
<td>Hours 10</td>
<td>-0.287</td>
<td>0.112</td>
<td>-0.6643</td>
<td>0.464</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
</tr>
<tr>
<td>(Hours 10)^2</td>
<td>0.000348</td>
<td>0.0000823</td>
<td>0.00112</td>
<td>0.00135</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
</tr>
<tr>
<td>Hours 10.Storage time</td>
<td>-0.000653</td>
<td>0.000240</td>
<td>-0.000465</td>
<td>0.00138</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
</tr>
<tr>
<td>Hours 10.Starch score</td>
<td>0.00797</td>
<td>0.0309</td>
<td>ne</td>
<td>ne</td>
<td>1.42</td>
<td>0.485</td>
<td>0.004**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hours 25</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>-0.00345</td>
<td>0.00130</td>
<td>0.008**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Hours 25)^2</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
</tr>
<tr>
<td>Hours 25.Storage time</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
</tr>
<tr>
<td>Hours 25.Starch score</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
</tr>
<tr>
<td>Storage time. Starch score</td>
<td>0.0259</td>
<td>0.0517</td>
<td>-0.0498</td>
<td>0.0797</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
<td>ne</td>
</tr>
</tbody>
</table>

**Range of predictor values used to determine fixed model coefficients**

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Yarra Valley</th>
<th>Adelaide Hills</th>
<th>Goulburn Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours 10</td>
<td>70 - 508</td>
<td>126 - 253</td>
<td>88 - 222</td>
</tr>
<tr>
<td>Hours 25^D</td>
<td>2.5 - 4.0</td>
<td>2.0 - 4.4</td>
<td>1.6 - 3.5</td>
</tr>
<tr>
<td>Starch score</td>
<td>112 - 224 days</td>
<td>78 - 183 days</td>
<td>107 - 246 days</td>
</tr>
<tr>
<td>Storage time</td>
<td>March 29 - April 28</td>
<td>April 9 - May 2</td>
<td>March 13 - March 29</td>
</tr>
</tbody>
</table>

^determined for angular-transformed percentages of scald incidence
^standard error of fixed model coefficient
^significance of Chi-squared probability of Wald test for dropping individual terms from full fixed model; * P < 0.05; ** P < 0.01
^determined between February 15 and harvest
ne - fixed model coefficient not estimated
5.3.2 Pink Lady

Adelaide Hills, South Australia

Scald incidence data was generated for ‘Pink Lady’ apples harvested from one orchard in the Adelaide Hills in South Australia during three seasons of trials. In 2000 high levels of ‘soft’ scald and rots in CA stored fruit from this district created difficulties in assessing superficial scald and so this data was omitted. The proposed prediction model has not been fitted to scald incidence due to a limited data set. An analysis of variance (ANOVA) of the angular-transformed percentage of fruit with scald obtained from 2001 and 2002 does provide some evidence that within each year scald susceptibility increases with longer storage periods in early-picked fruit (Table 5.4).

Table 5.4. Effect of time of removal and harvest date on scald incidence in ‘Pink Lady’ apples harvested from Adelaide Hills, SA in 2001 and 2002. Analysis of variance (ANOVA) performed on angular-transformed data. Values in italics represent back transformed means (% scald).

<table>
<thead>
<tr>
<th>Year</th>
<th>Removal from CA storage</th>
<th>Storage time</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>ss = 3.3</td>
<td>ss = 3.9</td>
<td>ss = 4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>h10 = 196</td>
<td>h10 = 228</td>
<td>h10 = 295</td>
</tr>
<tr>
<td>2001</td>
<td>1st</td>
<td>4 months</td>
<td>11.5</td>
<td>23.5</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>5 months</td>
<td>35.1</td>
<td>33.1</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.6</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>6 months</td>
<td>39.4</td>
<td>40.3</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5.7</td>
<td>9.1</td>
<td>2.5</td>
</tr>
<tr>
<td>2002</td>
<td>1st</td>
<td>5 months</td>
<td>46.6</td>
<td>52.8</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>6 months</td>
<td>64.7</td>
<td>81.7</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.8</td>
<td>1.8</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>8 months</td>
<td>73.4</td>
<td>91.8</td>
<td>22.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15.0</td>
<td>4.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

LSD of means (5% level) comparing a harvest at each removal: 10.6
LSD of means (5% level) comparing a removal at each harvest: 10.5

A Fruit starch score (ss) and accumulated preharvest hours below 10°C (h10) at each harvest

In addition,

- Mean scald incidence was significantly higher at each removal in 2002 compared to 2001, due to differences in the length of the storage period at each removal.
- There is a large effect of harvest date on scald incidence with fruit harvested early having significantly higher scald incidence at each removal within a year compared to apples picked later.
- Very low scald incidence was found on late harvested ‘Pink Lady’ apples from the Adelaide Hills with no significant difference in mean values between the first two removals in both years.
- For fruit picked early in both years the effect of removal time on scald incidence was significant with higher scald levels after the 2nd and 3rd removal compared to the 1st removal.

A limited amount of scald incidence data obtained so far for ‘Pink Lady’ apples in the Adelaide Hills suggests that a potentially useful prediction model may be fitted to a data set containing at least four years of results.
It is likely that in this mild district harvest date as measured by starch score or number of days from 1st February to harvest will be a good predictor of scald susceptibility. At this stage the data indicates that late-harvested fruit with a starch score above 3.5 are likely to be relatively scald-resistant when stored in CA for up to six months.

Batlow, NSW

‘Pink Lady’ apples were harvested from one ‘high elevation’ orchard in Batlow, NSW between 2000 and 2002 and scald incidence recorded after different removals from CA storage. Again in 2000 high levels of ‘soft’ scald’ in storage made it difficult to assess superficial scald and the data was omitted. Only years two years of scald incidence data the proposed prediction model was not fitted. An analysis of variance (ANOVA) was conducted on the angular-transformed percentage of fruit with scald recorded in 2001 and 2002 to determine if there was any effect of removal and harvest on scald susceptibility. A comparison of transformed treatment means indicate that in 2002 both time of removal and harvest date had a significant effect on the level of scald incidence (Table 5.5). The pattern of scald development was slightly different in 2001 when lower scald levels were recorded.

Table 5.5. Effect of time of removal and harvest date on scald incidence in ‘Pink Lady’ apples harvested from Batlow, NSW in 2001 and 2002. Analysis of variance (ANOVA) performed on angular-transformed data. Values in italics represent back transformed means (% scald).

<table>
<thead>
<tr>
<th>Year</th>
<th>Removal from CA storage</th>
<th>Storage time</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>1st</td>
<td>4 months</td>
<td>ss = 1.4</td>
<td>ss = 3.1</td>
<td>ss = 3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>h10 = 112</td>
<td>h10 = 158</td>
<td>h10 = 193</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>5 months</td>
<td>23.7</td>
<td>16.2</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>54.4</td>
<td>66.1</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>7 months</td>
<td>65.8</td>
<td>83.2</td>
<td>20.0</td>
</tr>
<tr>
<td>2002</td>
<td>1st</td>
<td>5 months</td>
<td>ss = 2.3</td>
<td>ss = 3.3</td>
<td>ss = 3.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>h10 = 80</td>
<td>h10 = 115</td>
<td>h10 = 183</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>6 months</td>
<td>46.6</td>
<td>52.8</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>64.7</td>
<td>81.7</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>8 months</td>
<td>73.4</td>
<td>91.8</td>
<td>22.8</td>
</tr>
</tbody>
</table>

LSD of means (5% level) comparing a harvest at each removal: 9.1
LSD of means (5% level) comparing a removal at each harvest: 8.3
\(^A\) Fruit starch score (ss) and accumulated preharvest hours below 10°C (h10) at each harvest

In addition,
- Mean scald incidence was significantly higher at each removal in 2002 compared to 2001, due to differences in the length of storage period at each removal.
- Scald incidence increases significantly with each time of removal for early harvest fruit in 2001 and between the 1st and 2nd removal in 2002.
- No scald was detected in middle and late-picked fruit after the 1st and 2nd removal from storage in 2001. A significant difference in scald incidence on fruit at each of these harvests was only found after the 3rd removal.
- In 2002 there was no significant difference in scald levels on fruit harvested late and removed from storage after five, six or eight months.
The significant effects of time of removal and harvest date indicate that with at least two more years of data prediction of scald susceptibility may be possible.

As changes in starch score correlate well with increasing preharvest hours below 10°C in this district either one of these would be expected to be a good predictor. It is likelier though that starch score will be a more appropriate predictor as accumulated preharvest hours were lower than expected. Based on two years of trials late harvested fruit with a starch score of 3.5 or greater are likely to have low scald susceptibility when stored in CA for up to five months.

**Yarra Valley, Victoria**

Accumulated preharvest hours below 10°C between 1st February and harvest was the most important predictor of scald susceptibility for ‘Pink Lady’ apples harvested from three orchards in the Yarra Valley in Victoria over five seasons between 1997 and 2002 (Table 5.6). A plot of mean scald incidence after 5 or 6 months storage for all years studied against accumulated preharvest hours below 10°C suggests that at each storage time scald incidence decreases substantially with increasing ‘cold’ temperatures before harvest (Figure 5.4).

![Figure 5.4](image)

**Figure 5.4.** Scald development in ‘Pink Lady’ apples harvested from the Yarra Valley in Victoria over five seasons and removed from storage after 5, 6 or 8 months in relation to preharvest hours below 10°C. Each point represents one year\times\text{harvest}\times\text{removal} combination.

In addition,

- The effect of preharvest hours below 10°C on scald incidence is highly significant.
- Minimum temperatures during April in the Yarra Valley consistently remain below 10°C for up to 12 hours per day resulting in fruit harvested late being exposed to many accumulated preharvest hours.
- Storage time does have an effect on scald incidence for ‘Pink Lady’ from this district based on the significance of the $(\text{storage time})^2$ term in the fitted model ie. Fruit stored for short storage times develops little or no scald.
- The interaction between preharvest hours and starch score is also significant (at the 5% level) although the actual relationship has not been determined. A plot of preharvest hours against starch score at harvest for this district and cultivar indicates that fruit maturity is correlated with accumulation of preharvest hours (Figure 5.5).
Figure 5.5. Relationship between fruit starch score at harvest and preharvest hours below 10°C for ‘Pink Lady’ apples harvested from the Yarra Valley in Victoria over five seasons. Each point represents one year × harvest combination.

The wide range of preharvest hours recorded over five seasons will enable the further development of a useful predictive model for this cultivar in the Yarra Valley. Fruit accumulating more than approximately 400 preharvest hours below 10°C and stored for up to five months in CA is likely to have very low scald susceptibility. Fruit exposed to greater than 500 preharvest hours have the potential to be stored in CA for six to seven months without the use of DPA.

Huonville, Tasmania

Scald incidence data generated for ‘Pink Lady’ apples harvested from one orchard in Huonville, Tasmania during three seasons of trials shows that accumulated preharvest hours below 10°C between 1st February and harvest is an important predictor of scald susceptibility in this district (Table 5.6). A plot of mean scald incidence after five or six months storage for all years studied as a function of accumulated preharvest hours below 10°C demonstrates that a strong relationship is likely between scald susceptibility and increasing ‘cold’ temperatures before harvest (Figure 5.6).

In addition,
- The significance of both the hour10 and \((\text{hour10})^2\) terms in the fitted model shows that this relationship is likely to have both a curvilinear and linear component ie. Scald falls rapidly as preharvest hours increase.
- A complex relationship exists between scald incidence, harvest data and storage time for ‘Pink Lady’ in this district. There is a highly significant interaction between time of removal and both preharvest hours below 10°C and starch score even though the linear term for each of these variables is not significant in itself.
- The significance of the hour10.storage time and storage time.starch score terms shows that fruit maturity and preharvest hours will have different effects on the level of scald incidence depending on the storage time.
- Storage time does have a significant effect on scald incidence for ‘Pink Lady’ from this district based on the significance of the \((\text{storage time})^2\) term in the fitted model as demonstrated by a plot of mean scald incidence against storage time (Figure 5.7) for all years studied.
- Further analysis is required to determine the most important storage time term in the model.
- The linear starch score term in the model was not a significant predictor of scald incidence as fruit maturity usually changed very little during the harvest period used in trials.
Figure 5.6. Effect of preharvest hours below 10°C on scald incidence in ‘Pink Lady’ apples harvested from Huonville, Tasmania over three seasons after storage for 5 or 6 months. Each point represents one year × harvest × removal combination.

Figure 5.7. Effect of number of days between harvest and removal on scald incidence in ‘Pink Lady’ apples harvested from Huonville, Tasmania over three seasons. Each point represents one year × harvest × removal combination.

A potentially useful predictive model can be developed from the data obtained so far but one or two more years of trials that include a wider range of storage periods should enhance the applicability of the model. The relatively large range of preharvest hours recorded over three years suggests that fruit accumulating more than approximately 250 preharvest hours below 10°C and stored for up to six months in CA is likely to have low scald susceptibility.
Goulburn Valley, Victoria

Starch score at harvest as an indicator of fruit maturity was a significant predictor of scald susceptibility for ‘Pink Lady’ apples harvested from two orchards in the Goulburn Valley in Victoria over six seasons between 1997 and 2002 (Table 5.6). Accumulated preharvest hours below 10°C and time of removal were also important predictors of scald incidence. A plot of mean scald incidence against fruit starch score at harvest after five, six or seven months storage for all years studied suggests that scald incidence decreases significantly with increasing fruit maturity at harvest (Figure 5.8). Again the importance of each predictor and their interactions are complex for ‘Pink Lady’ apples grown in this district (Table 5.6).

![Figure 5.8](image)

**Figure 5.8.** Effect of starch score at harvest on scald incidence in ‘Pink Lady’ apples picked from the Goulburn Valley in Victoria over six seasons and removed from storage after 5 or 6 months. Each point represents one year×harvest ×removal combination.

In addition,
- There are small but significant effects of preharvest hours below 10°C, starch score at harvest and time of removal on scald incidence in ‘Pink Lady’ apples from this district.
- The interaction between starch score and preharvest hours is highly significant (at the 1% level) demonstrating that they are highly correlated over the wide range of preharvest hours and starch scores recorded. This may imply that the effect of preharvest hours on scald incidence increases at higher starch scores.
- Although the Goulburn Valley is a ‘hot’ growing district there is an appreciable accumulation of preharvest hours during April and early May and a corresponding effect on scald susceptibility (Figure 5.9).
- Storage time does have a significant effect on scald incidence for ‘Pink Lady’ from this district based on the significance of the \((storage\ time)^2\) term. Further analysis is required to determine the most important storage time term in the model.
- There is a significant interaction between starch score at harvest and the level of scald incidence at each removal as demonstrated by the significance of the \(storage\ time\_starch\ score\) term in the proposed model. Fruit with a starch score at harvest of 4.0 or greater is likely to have a low scald susceptibility when stored for up to six months in CA.

Fruit exposed to greater than 250 preharvest hours have the potential to be stored in CA for six to seven months using reduced DPA rates.
The wide range of starch scores and preharvest hours recorded over six seasons will allow the future development of a useful and robust predictive model for this cultivar in the Goulburn Valley. As ‘Pink Lady’ apples in this district are generally harvested relatively late to allow for colour development there is a real opportunity to utilise a scald development model and reduce or eliminate DPA use. An important consideration though is that mature fruit at harvest can only be stored for a relatively short time, that is, for less than six months due to rapid quality loss in storage.

Figure 5.9. Effect of preharvest hours below 10°C on scald incidence in ‘Pink Lady’ apples harvested from the Goulburn Valley in Victoria over three seasons and removed from storage after 5, 6 or 7 months. Each point represents one year × harvest × removal combination.
Table 5.6. Linear mixed model and data range used for fitting orchard temperature, maturity and storage time to the angular transformed percentage of scald incidence for ‘Pink Lady’ apples from three districts.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Yarra Valley</th>
<th></th>
<th>Hounville</th>
<th></th>
<th>Goulburn Valley</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed model coefficients</td>
<td>s.e.</td>
<td>Chi-squared</td>
<td>prob</td>
<td>Fixed model coefficients</td>
<td>s.e.</td>
</tr>
<tr>
<td>Constant</td>
<td>110</td>
<td>67.7</td>
<td>70.2</td>
<td>0.0134</td>
<td>0.000415</td>
<td>0.001**</td>
</tr>
<tr>
<td>Storage time</td>
<td>-0.214</td>
<td>0.208</td>
<td>0.304</td>
<td>-0.277</td>
<td>0.194</td>
<td>0.153</td>
</tr>
<tr>
<td>(Storage time)$^2$</td>
<td>0.00159</td>
<td>0.000376</td>
<td>&lt;0.001**</td>
<td>0.00134</td>
<td>0.000415</td>
<td>0.001**</td>
</tr>
<tr>
<td>Starch score</td>
<td>20.3</td>
<td>48.4</td>
<td>0.675</td>
<td>15.2</td>
<td>17.8</td>
<td>0.395</td>
</tr>
<tr>
<td>(Starch score)$^2$</td>
<td>-14.6</td>
<td>10.8</td>
<td>0.175</td>
<td>-5.44</td>
<td>3.00</td>
<td>0.070</td>
</tr>
<tr>
<td>Hours10</td>
<td>-0.774</td>
<td>0.248</td>
<td>0.002**</td>
<td>-0.2568</td>
<td>0.0999</td>
<td>0.010*</td>
</tr>
<tr>
<td>(Hours10)$^2$</td>
<td>-0.000900</td>
<td>0.000502</td>
<td>0.073</td>
<td>0.000436</td>
<td>0.000960</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Hours10.Storage time</td>
<td>-0.000219</td>
<td>0.000164</td>
<td>0.184</td>
<td>-0.001083</td>
<td>0.000249</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Hours10.Starch score</td>
<td>0.332</td>
<td>0.130</td>
<td>0.010*</td>
<td>0.153</td>
<td>0.045</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Storage time.Starch score</td>
<td>-0.0406</td>
<td>0.0327</td>
<td>0.214</td>
<td>0.125</td>
<td>0.0255</td>
<td>&lt;0.001**</td>
</tr>
</tbody>
</table>

Range of predictor values used to determine fixed model coefficients

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Range of predictor values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours10</td>
<td>95 - 436</td>
</tr>
<tr>
<td>Starch score</td>
<td>2.3 - 4.6</td>
</tr>
<tr>
<td>Storage time</td>
<td>113 - 248 days</td>
</tr>
<tr>
<td>Harvest date</td>
<td>April 9 - May 3</td>
</tr>
</tbody>
</table>

*a* determined for angular-transformed percentages of scald incidence

*b* standard error of fixed model coefficient

*c* significance of Chi-squared probability of Wald test for dropping individual terms from full fixed model; *P* < 0.05; **P** < 0.01.
5.3.3 Red Delicious

Superficial scald was relatively difficult to assess on ‘Red Delicious’ cultivars used in forecasting trials compared with other varieties regardless of the district from which they were harvested. Unless otherwise stated, discolouration and scald were assessed as a single ‘scald’ disorder, as it was almost impossible to distinguish between the two particularly when superficial scald was not severe i.e. After a short storage period or on mature fruit.

In this study discolouration is defined as a loss of background colour from green to brown during storage with no evidence of pitting or skin-cell death as for superficial scald. It was usually found on the green surface of fruit and in some cases, may have been the beginning of scald development, although senescence in storage or discolouration at harvest could have also been factors. Most of the ‘Red Delicious’ samples assessed included fruit displaying scald of varying degrees of severity (Figure 5.10). In some districts such as Batlow the degree of severity was relatively low and the majority of fruit displaying scald-like symptoms would not have been downgraded for the fresh market.

![Figure 5.10](image)

**Figure 5.10.** ‘Red Delicious’ apples displaying severe superficial scald (left) and brown discolouration (right) that may be the initial stages of scald development.
Yarra Valley, Victoria

Fruit maturity as measured by starch score at harvest was the most important predictor of scald susceptibility for ‘Red Chief’ apples harvested from two orchards in the Yarra Valley in Victoria over six seasons between 1995 and 2002 (Table 5.7). A plot of mean scald incidence after 5 or 6 months storage for all years studied against starch score at harvest indicates that scald incidence is relatively low in apples from this district within the range of starch scores recorded (Figure 5.11). It also tends to decrease with increasing fruit maturity at harvest.

In addition,

- The effects of starch score at harvest on scald and discolouration incidence is highly significant.
- Accumulated preharvest hours below 10°C also has a small effect on scald susceptibility at the 5% significance level.
- During March fruit in this district are exposed to relatively few accumulated preharvest hours below 10°C. Use of a ‘threshold’ temperature of 12°C rather than 10°C may improve the relationship between ‘cold’ temperatures and incidence of scald and discolouration.
- Storage time does not have a significant effect on scald and discolouration incidence for ‘Red Chief’ harvested from this district within the range of removal times used in forecasting trials.
- There is no significant interaction between preharvest hours and starch score indicating that ‘Red Chief’ maturity changes relatively slowly compared to accumulation of preharvest hours in this district.

![Figure 5.11](image-url)

**Figure 5.11.** Effect of fruit starch score at harvest on incidence of scald and discolouration in ‘Red Chief’ apples harvested from the Yarra Valley in Victoria over six seasons and removed from storage after 5 or 6 months. Each point represents one year × harvest × removal combination.
Table 5.7. Linear mixed model and data range used for fitting orchard temperature, maturity and storage time to the angular transformed percentage of scald and discolouration incidence for ‘Red Chief’ apples harvested from the Yarra Valley in Victoria.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Fixed model coefficients&lt;sup&gt;A&lt;/sup&gt;</th>
<th>s.e.&lt;sup&gt;B&lt;/sup&gt;</th>
<th>Chi-squared prob&lt;sup&gt;C&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>148</td>
<td>50.6</td>
<td>0.767</td>
</tr>
<tr>
<td>Storage time</td>
<td>-0.0714</td>
<td>0.241</td>
<td>0.792</td>
</tr>
<tr>
<td>(Storage time)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.000128</td>
<td>0.000484</td>
<td>0.792</td>
</tr>
<tr>
<td>Starch score</td>
<td>-99.5</td>
<td>35.4</td>
<td>0.005**</td>
</tr>
<tr>
<td>(Starch score)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>21.3</td>
<td>7.95</td>
<td>0.008**</td>
</tr>
<tr>
<td>Hours10</td>
<td>-0.112</td>
<td>0.307</td>
<td>0.717</td>
</tr>
<tr>
<td>(Hours10)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.00249</td>
<td>0.00102</td>
<td>0.015*</td>
</tr>
<tr>
<td>Hours10.Storage time</td>
<td>-0.000580</td>
<td>0.000424</td>
<td>0.171</td>
</tr>
<tr>
<td>Hours10.Starch score</td>
<td>-0.267</td>
<td>0.168</td>
<td>0.111</td>
</tr>
<tr>
<td>Storage time.Starch score</td>
<td>0.105</td>
<td>0.0579</td>
<td>0.069</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Range of predictor values used to determine fixed model coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours10</td>
<td>31 - 159</td>
</tr>
<tr>
<td>Starch score</td>
<td>1.6 - 2.8</td>
</tr>
<tr>
<td>Storage time</td>
<td>108 - 243 days</td>
</tr>
<tr>
<td>Harvest date</td>
<td>March 5 - March 28</td>
</tr>
</tbody>
</table>

<sup>A</sup>determined for angular-transformed percentages of scald incidence  
<sup>B</sup>standard error of fixed model coefficient  
<sup>C</sup>significance of Chi-squared probability of Wald test for dropping individual terms from full fixed model; * <i>P < 0.05</i>; ** <i>P < 0.01</i>.

A comprehensive data set collected over six years of trials for ‘Red Chief’ harvested from this district will enable the further development of a robust predictive model. As superficial scald severity in this cultivar from the Yarra Valley is usually low and in many cases cannot be distinguished from discolouration, any model developed will likely provide an “over-estimate” of actual superficial scald susceptibility.

This suggests that there will be a ‘safety factor’ inherent in predictions made using the final forecasting model. With this knowledge growers will be able to use scald susceptibility information at harvest with considerable confidence and potentially reduce or eliminate DPA use.
Batlow, NSW

Scald incidence data was generated for ‘Red Delicious’ apples harvested from two ‘low elevation’ orchards and one ‘high elevation’ orchard in Batlow, NSW during three seasons of trials. A study of scald incidence data collected in 2000 suggests that fruit were only assessed for severe superficial scald resulting in very low incidence levels being recorded. In 2001 and 2002 apples with any scald-type symptom including discoulouration were assessed as having ‘scald’. For consistency only the last two years of scald and discoulouration incidence data were used in statistical analyses and so the proposed prediction model was not fitted. An analysis of variance (ANOVA) of the angular-transformed percentage of fruit with scald and discoulouration obtained from ‘low elevation’ orchards in 2001 and 2002 does provide some evidence that within each year scald susceptibility significantly changes with longer storage periods in early-picked fruit (Table 5.8).

Table 5.8. Effect of time of removal and harvest date on scald and discoulouration incidence in ‘Red Delicious’ apples harvested from two ‘low elevation’ orchards in Batlow, NSW in 2001 and 2002. Analysis of variance (ANOVA) performed on angular-transformed combined scald and discoulouration data. Values in italics represent back transformed means (%scald and discoulouration).

<table>
<thead>
<tr>
<th>Year</th>
<th>Removal from CA storage</th>
<th>Storage time</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>1st</td>
<td>4 months</td>
<td>ss = 1.4&lt;sup&gt;A&lt;/sup&gt;</td>
<td>ss = 1.6</td>
<td>ss = 1.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>h10 = 9</td>
<td>h10 = 19</td>
<td>h10 = 67</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>5 months</td>
<td>4.4</td>
<td>0.6</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>6 months</td>
<td>19.3</td>
<td>10.9</td>
<td>7.5</td>
</tr>
<tr>
<td>2002</td>
<td>1st</td>
<td>4 months</td>
<td>ss = 1.5</td>
<td>ss = 1.6</td>
<td>ss = 2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>h10 = 43</td>
<td>h10 = 46</td>
<td>h10 = 49</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>5 months</td>
<td>8.3</td>
<td>2.1</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.5</td>
<td>0.2</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>6 months</td>
<td>10.4</td>
<td>3.3</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4.3</td>
<td>0.6</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9.1</td>
<td>2.5</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.1</td>
<td>10.7</td>
<td>9.1</td>
</tr>
</tbody>
</table>

LSD of means (5% level) comparing a harvest at each removal: 8.4
LSD of means (5% level) comparing a removal at each harvest: 9.0

<sup>A</sup> Fruit starch score (ss) and accumulated preharvest hours below 10°C (h10) at each harvest

In addition,
- Severity of scald and discoulouration was relatively low in ‘Red Delicious’ harvested from ‘low elevation’ orchards ie. Less than 20% of fruit surface area (data not shown).
- Scald and discoulouration incidence was very low in both years in fruit from middle and late harvests with no significant effect due to time of removal or harvest date.
- In 2001 early picked fruit had significantly higher incidence of scald and discoulouration at the 2<sup>nd</sup> and 3<sup>rd</sup> removal compared to the 1<sup>st</sup> removal and to later harvested fruit stored for the same length of time.
- In 2002 the same pattern was found as in 2001 except that in this year early harvested apples had significantly higher scald and discoulouration incidence at the 3<sup>rd</sup> removal compared to the first two removals.
- Although Batlow is perceived as a ‘cool’ apple-growing district, during March fruit are exposed to very few accumulated preharvest hours below 10°C or 12°C and it is very likely that preharvest hours is not a good predictor for ‘Red Delicious’ at ‘low’ elevations.
• Within the three-week harvest period used in trials starch score at harvest changed only marginally and further trials including earlier and later harvests may be required to determine if fruit maturity influences scald susceptibility.

An analysis of variance (ANOVA) of the angular-transformed percentage of fruit with scald and discolouration obtained from a ‘high elevation’ orchard in 2001 and 2002 indicates that within each year fruit maturity at harvest has a significant effect on scald and discolouration incidence after the 1st removal (Table 5.9).

In addition,
• Early harvest ‘Red Delicious’ apples had significantly higher levels of scald and discolouration than middle and late harvest fruit after the 1st and 2nd removal in 2001 but only after the 1st removal in 2002.
• Severity of scald and discolouration was again relatively low in ‘Red Delicious’ harvested from the ‘high elevation’ orchard although higher than ‘low elevation’ orchards’ in the same district. This is a surprising outcome considering that ‘high elevation’ fruit generally had a higher starch score and had been exposed to more preharvest hours.
• Fruit from the ‘high elevation’ orchard accumulated many more preharvest hours below 10°C or 12°C than ‘low elevation’ orchards suggesting that this may be a possible predictor of scald incidence in ‘Red Delicious’ apples from higher elevations in this district.
• Scald and discolouration incidence was low in both years in fruit from middle and late harvests with no significant effect of harvest date. In 2002 late harvested apples removed after four and five months storage had significantly different scald and discolouration incidence.
• It is unlikely that in 2001 early and late harvest fruit had significantly less scald and discolouration incidence after the 3rd removal in comparison to the 2nd removal as shown in Table 9. These lower values were most likely caused by difficulty in distinguishing between discolouration due to senescence and scald-like symptoms during assessment.

Scald and discolouration incidence data collected from Batlow, NSW for ‘Red Delicious’ apples suggests that middle and late harvested fruit have low scald susceptibility when stored for up to six months. Further analysis is required to determine if starch score at harvest and storage time will be good predictors of scald susceptibility. Two more years of scald incidence data may enable the development of ‘low elevation’ and ‘high elevation’ prediction models for this cultivar.

As little evidence of severe superficial scald on fruit was found during assessments it is likely that DPA rates can be significantly reduced or even eliminated for middle and late harvested apples stored for up to six months with minimal risk of increasing the levels of unmarketable fruit. Although an accurate prediction model would be beneficial to growers in this district the results obtained so far can be used to guide scald management decisions at harvest.
Table 5.9. Effect of time of removal and harvest date on discolouration and scald incidence in ‘Red Delicious’ apples harvested from a ‘high elevation’ orchard in Batlow, NSW in 2001 and 2002. Analysis of variance (ANOVA) performed on angular-transformed combined scald and discolouration data. Values in italics represent back transformed means (%scald and discolouration).

<table>
<thead>
<tr>
<th>Year</th>
<th>Removal from CA storage</th>
<th>Storage time</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>1st</td>
<td>4 months</td>
<td>ss = 2.2\textsuperscript{a}</td>
<td>ss = 2.4</td>
<td>ss = 2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>h10 = 52</td>
<td>h10 = 125</td>
<td>h10 = 167</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>5 months</td>
<td>20.8</td>
<td>12.6</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>27.0</td>
<td>20.6</td>
<td>12.1</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>6 months</td>
<td>17.9</td>
<td>9.4</td>
<td>12.3</td>
</tr>
<tr>
<td>2002</td>
<td>1st</td>
<td>4 months</td>
<td>ss = 1.8</td>
<td>ss = 1.9</td>
<td>ss = 2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>h10 = 99</td>
<td>h10 = 116</td>
<td>h10 = 129</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>5 months</td>
<td>11.6</td>
<td>4.0</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15.3</td>
<td>7.0</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>6 months</td>
<td>18.0</td>
<td>9.6</td>
<td>12.4</td>
</tr>
</tbody>
</table>

LSD of means (5% level) comparing a harvest at each removal: 8.7
LSD of means (5% level) comparing a removal at each harvest: 8.9
\textsuperscript{a} Fruit starch score (ss) and accumulated preharvest hours below 10°C (h10) at each harvest
Hi Early and Tas Ag8 ‘Red Delicious’ apples were harvested from one orchard in Huonville, Tasmania between 2000 and 2002 and scald incidence recorded after different removals from CA storage. Again in 2000 only scald incidence was recorded and with only two years of scald and discolouration incidence data the proposed prediction model was not fitted. An analysis of variance (ANOVA) was conducted on the angular-transformed percentage of fruit with scald and discolouration recorded in 2001 and 2002 to determine if there was any effect of removal and harvest on scald susceptibility. For Hi Early a comparison of transformed treatment means indicates that in 2001 there was a significant effect of harvest date on scald and discolouration incidence at the 2nd and 3rd removal. The effect of removal time was only significant between the 1st and later removals for early harvest fruit (Table 5.10).

Tas Ag8 was more susceptible to scald and discolouration compared to Hi Early over the removals and harvest dates used it trials. In 2001 both harvest date and time of removal had a significant effect on the level of scald incidence (Table 5.11). The pattern of scald development was slightly different in 2002 when lower scald levels were recorded.

In addition,
- No scald or discolouration was recorded on Hi Early apples picked from this district in 2002 at all removals and harvest dates.
- Accumulated preharvest hours below 10°C at each harvest for both Hi Early and Tas Ag8 fruit was higher in 2002 compared to 2001 and the lowest preharvest hours in 2002 was higher than that accumulated at the late harvest in 2001.
- In 2001 Tas Ag8 had significantly higher scald and discolouration incidence at the 2nd and 3rd removal compared to the 1st removal at each harvest. In 2002 there was no significant difference in scald and discolouration between the 1st and 2nd removal for early and late harvest fruit.
- In 2001 at each removal late harvest Tas Ag8 fruit had significantly lower scald and discolouration incidence compared to early and middle picked apples in this district. No such pattern occurred in 2002 when lower incidence was recorded and harvest date was not a significant factor.

Table 5.10. Effect of time of removal and harvest date on discolouration and scald incidence in Hi Early ‘Red Delicious’ apples harvested from Huonville, Tasmania in 2001 and 2002. Analysis of variance (ANOVA) performed on angular-transformed combined scald and discolouration data. Values in italics represent back transformed means (%scald and discolouration).

<table>
<thead>
<tr>
<th>Year</th>
<th>Removal from CA storage</th>
<th>Storage time</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>ss</td>
<td>nr</td>
<td>nr</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>h10 = 177</td>
<td>h10 = 202</td>
<td>h10 = 267</td>
</tr>
<tr>
<td>2001</td>
<td>1st</td>
<td>4 months</td>
<td>1.8</td>
<td>6.0</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 months</td>
<td>22.9</td>
<td>12.2</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 months</td>
<td>23.5</td>
<td>10.0</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>1st</td>
<td>4 months</td>
<td>1.7</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>5 months</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>6 months</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

LSD of means (5% level) comparing a harvest at each removal: 8.7
LSD of means (5% level) comparing a removal at each harvest: 8.9

A Fruit starch score (ss) and accumulated preharvest hours below 10°C (h10) at each harvest
nr - not recorded

40
Early indications are that *Hi Early* ‘Red Delicious’ picked from Huonville in Tasmania have very low scald susceptibility once exposed to more than 250 accumulated preharvest hours below 10°C and stored for up to six months (Figure 5.12).

With two more years of scald data collected from this district a useful prediction model can be developed for this cultivar based on preharvest ‘cold’ temperatures.

For *Tas Ag8* apples harvested from this district it is likely that exposure to more than 300 accumulated preharvest hours below 10°C will be required before fruit have low scald susceptibility and can be stored up to five months in CA without DPA (Figure 5.12). A robust predictive model is possible for this ‘Red Delicious’ strain if more scald data is obtained from further trials.

**Table 5.11.** Effect of time of removal and harvest date on discolouration and scald incidence in *Tas Ag8* ‘Red Delicious’ apples harvested from Huonville, Tasmania in 2001 and 2002. Analysis of variance (ANOVA) performed on angular-transformed combined scald and discolouration data. Values in *italics* represent back transformed means (%scald and discolouration).

<table>
<thead>
<tr>
<th>Year</th>
<th>Removal from CA storage</th>
<th>Storage time</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td><strong>1st</strong></td>
<td>4 months</td>
<td>ss = 2.0&lt;sup&gt;A&lt;/sup&gt;</td>
<td>h10 = 123</td>
<td>26.9</td>
</tr>
<tr>
<td></td>
<td><strong>2nd</strong></td>
<td>5 months</td>
<td>ss = 2.0</td>
<td>h10 = 168</td>
<td>23.4</td>
</tr>
<tr>
<td></td>
<td><strong>3rd</strong></td>
<td>6 months</td>
<td>ss = 2.0</td>
<td>h10 = 177</td>
<td>10.8</td>
</tr>
<tr>
<td>2002</td>
<td><strong>1st</strong></td>
<td>4 months</td>
<td>ss = 1.1</td>
<td>h10 = 195</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td><strong>2nd</strong></td>
<td>5 months</td>
<td>ss = 1.1</td>
<td>h10 = 263</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td><strong>3rd</strong></td>
<td>6 months</td>
<td>ss = 1.7</td>
<td>h10 = 296</td>
<td>8.9</td>
</tr>
</tbody>
</table>

LSD of means (5% level) comparing a removal at each harvest: 8.4

LSD of means (5% level) comparing a harvest at each removal: 8.8

<sup>A</sup> Fruit starch score (ss) and accumulated preharvest hours below 10°C (h10) at each harvest

**Figure 5.12.** Effect of preharvest hours below 10°C on incidence of scald and discolouration in *Hi Early* and *Tas Ag8* ‘Red Delicious’ apples harvested from Huonville, Tasmania in 2001 and 2002 and removed from storage after 5 months. Each point represents one year × harvest × removal combination.
Other districts

Scald forecasting trials were also conducted on ‘Red Delicious’ apples harvested from Stanley and Narre Warren in Victoria, and Adelaide Hills in South Australia. Due to limited data sets obtained from less than three years of trials or different experimental designs used between years a full analysis of the scald data was not possible. The key results of these trials are briefly discussed below.

Although ‘Red Delicious’ apples were harvested from Stanley in Victoria over three seasons the scald incidence results were inconclusive as fruit was only harvested more than once in a single year in 2000. In this season no scald was recorded after four, five or six months storage in CA on fruit from this district harvested between the 15th and 28th March. Fruit starch score at harvest and accumulated preharvest hours below 10°C are detailed in Table 5.12. The orchard used for trials in Stanley was located 300 metres above sea level but air temperature during March does not consistently fall below 10°C resulting in relatively few accumulated preharvest hours. This result suggests that ‘Red Delicious’ from this district are relatively scald-resistant when stored for less than six months with a starch score at harvest above 1.7. It should be noted that the high anthocyanin content of apples assessed from Stanley made identification of scald symptoms difficult.

Table 5.12. Range of starch scores at harvest, storage times, harvest dates and preharvest hours accumulated within which no scald incidence was recorded for ‘Red Delicious’ harvested from Stanley in Victoria in 2000.

<table>
<thead>
<tr>
<th>Storage Time (months)</th>
<th>Harvest Date</th>
<th>Starch Score</th>
<th>Hours &lt;10°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>4, 5 or 6</td>
<td>15/03</td>
<td>1.74</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>21/03</td>
<td>1.69</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>28/03</td>
<td>1.92</td>
<td>139</td>
</tr>
</tbody>
</table>

In both 1997 and 1998 ‘Red Delicious’ apples were harvested from Narre Warren in Victoria at the commercial harvest date and fruit samples removed from CA storage after four, five, six or eight months. Fruit from this district was red to brown in colour at harvest and was difficult to assess for superficial scald out of storage. Fruit were exposed to almost no preharvest hours below 10°C in this warm district and susceptibility to scald and discolouration was relatively high and increased with longer periods in storage (Figure 5.13).

High scald incidence was recorded in ‘Red Delicious’ harvested from the Adelaide Hills in South Australia during one season of trials. Severe scald occurred irrespective of harvest date or time of removal (data not shown). This result is inconclusive as only one year of scald incidence data was collected.
Figure 5.13. Effect of number of days in CA storage between harvest and removal on incidence of scald and discolouration in ‘Red Delicious’ apples harvested from Narre Warren, Victoria in 1997 and 1998, and removed from storage after 4, 5, 6 or 8 months. Each point represents one year×harvest ×removal combination.
5.3.4 Fuji

Huonville, Tasmania

Scald incidence data was generated for ‘Fuji’ apples harvested from one orchard in Huonville, Tasmania during two seasons of trials. The proposed prediction model has not been fitted to scald incidence due to a limited data set. An analysis of variance (ANOVA) performed for each year of the angular-transformed percentage of fruit with scald does provide some evidence that within each year scald susceptibility increases with longer storage periods and that harvest date only has a significant effect at the 3rd removal (Table 5.13). A plot of mean scald incidence after six, seven or eight months storage against accumulated preharvest hours below 10°C with both years included verifies that scald incidence is very low up until removal from storage after eight months (Figure 5.14).

In addition,

- In 2001 no scald was detected on ‘Fuji’ apples picked at early and middle harvest until the 3rd removal when there was a significant increase in scald incidence.
- Also in 2001 middle harvest fruit from this district had significantly less scald than early picked apples at the 3rd removal.
- Early harvest ‘Red Delicious’ apples had significantly higher levels of scald and discolouration than middle and late harvest fruit at the 1st and 2nd removal in 2001 but only at the 1st removal in 2002.
- The pattern of scald development was the same in 2002 with no scald detected in fruit stored in CA for 6 months but higher scald incidence at each harvest-removal combination.

Table 5.13. Effect of time of removal and harvest date on scald incidence in ‘Fuji’ apples harvested from Huonville, Tasmania in 2001 and 2002. Analysis of variance (ANOVA) performed separately for each year on angular-transformed percentage of fruit with scald. Values in italics represent back transformed means (%scald).

<table>
<thead>
<tr>
<th>Year</th>
<th>Removal from CA storage</th>
<th>Storage time</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>1st</td>
<td>5 months</td>
<td>nr</td>
<td>nr</td>
<td>h10 = 368&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>6 months</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>7 months</td>
<td>12.1</td>
<td>4.4</td>
<td>5.6</td>
</tr>
<tr>
<td>2002</td>
<td>1st</td>
<td>6 months</td>
<td>nr</td>
<td>nr</td>
<td>h10 = 453</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>7 months</td>
<td>0.0</td>
<td>0.0</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>8 months</td>
<td>31.1</td>
<td>26.7</td>
<td>23.8</td>
</tr>
</tbody>
</table>

LSD of means (5% level) comparing a harvest at each removal in 2001: 2.7
LSD of means (5% level) comparing a removal at each harvest in 2001: 2.3
LSD of means (5% level) comparing a harvest at each removal in 2002: 7.5
LSD of means (5% level) comparing a removal at each harvest in 2002: 6.9

<sup>A</sup> Accumulated preharvest hours below 10°C (h10) at each harvest
nr - not recorded
Figure 5.14. Effect of preharvest hours below 10°C and storage time on scald incidence in ‘Fuji’ apples harvested from Huonville, Tasmania in 2001 and 2002 and removed from storage after 6, 7 or 8 months. Each point represents one year×harvest ×removal combination.

Scald incidence data collected over two seasons indicates that ‘Fuji’ apples harvested from Huonville, Tasmania are relatively scald resistant within the range of harvest dates studied when stored in CA for up to seven months.
5.3.5 Jonagold

Huonville, Tasmania

Scald incidence data was generated for ‘Jonagold’ apples harvested from one orchard in Huonville, Tasmania during two seasons of trials. The proposed prediction model has not been fitted to scald incidence due to a limited data set. An analysis of variance (ANOVA) performed on the angular-transformed percentage of fruit with scald recorded in 2002 indicates that in this season scald susceptibility increased with longer storage periods and that harvest date also had a significant effect on scald incidence (Table 5.14). No superficial scald was recorded irrespective of harvest date or removal in 2001. A plot of mean scald incidence after five, six or seven months storage in 2002 against a maturity index at harvest measuring the percentage of cut apple surface stained black suggests that scald incidence remains very low until seven months in CA storage (Figure 5.15). A decreasing percentage of stained apple surface at harvest corresponds to increasing fruit maturity. In trials using this cultivar starch score was not an accurate measure of apple maturity at harvest as it was not determined based on colour plates but rather estimated from the surface staining results.

In addition,
- In 2002 scald incidence increased significantly at each removal for early harvest ‘Jonagold’ apples from this district but was only significantly different at the 3rd removal in late picked fruit.
- Scald incidence also decreased significantly at each harvest date in apples removed from CA storage after seven months. After 1st and 2nd removals scald levels were only significantly lower in late picked fruit.
- Irrespective of time of removal ‘Jonagold’ apples harvested late in 2002 had very low scald incidence levels.

**Table 5.14.** Effect of time of removal and harvest date on scald incidence in ‘Jonagold’ apples harvested from Huonville, Tasmania in 2001 and 2002. Analysis of variance (ANOVA) performed for 2002 data on angular-transformed percentage of fruit with scald. Values in *italics* represent back transformed means (%scald).

<table>
<thead>
<tr>
<th>Year</th>
<th>Removal from CA storage</th>
<th>Storage time</th>
<th>Harvest</th>
<th>Early</th>
<th>Middle</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>%Black = 20^8</td>
<td>%Black = 10</td>
<td>%Black = 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>h10 = 177^a</td>
<td>h10 = 267</td>
<td>h10 = 322</td>
</tr>
<tr>
<td>2001</td>
<td>1st</td>
<td>5 months</td>
<td>Early</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Middle</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>6 months</td>
<td>Early</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Middle</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>3rd</td>
<td>7 months</td>
<td>Early</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Middle</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2002</td>
<td>1st</td>
<td>5 months</td>
<td>Early</td>
<td>2.5</td>
<td>0.2</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Middle</td>
<td>11.8</td>
<td>4.2</td>
<td>12.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.8</td>
<td>4.8</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Late</td>
<td>20.8</td>
<td>12.6</td>
<td>15.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.8</td>
<td>1.0</td>
<td>5.6</td>
</tr>
</tbody>
</table>

LSD of means (5% level) comparing a harvest at each removal in 2002: 4.3
LSD of means (5% level) comparing a removal at each harvest in 2002: 4.1
^a Accumulated preharvest hours below 10°C (h10) at each harvest
^b Fruit maturity at each harvest as measured by the % cut apple surface stained black
Figure 5.15  Effect of fruit maturity at harvest and storage time on scald incidence in ‘Jonagold’ apples harvested from Huonville, Tasmania in 2002 and removed from storage after 5, 6 or 7 months. Each point represents one year×harvest×removal combination.

Scald incidence data collected over two seasons indicates that ‘Jonagold’ apples harvested from Huonville, Tasmania are relatively scald resistant within the range of harvest dates studied when stored in CA for up to six months.
5.3.6 Gala

Batlow, NSW

Two years of forecasting trials assessing the scald susceptibility of ‘Gala’ apples harvested from one orchard in Batlow, NSW showed that this cultivar is very scald resistant over a wide range of storage times, harvest dates and starch scores at harvest. No scald was recorded in 2000 and 2001 in fruit harvested between 20th February and 8th March with a starch score at harvest ranging between 2.0 and 4.8 (Table 5.15). Storage times studied ranged from four to eight months. Accumulated preharvest hours below 10°C doesn’t seem to be a factor influencing scald susceptibility of ‘Gala’ in this district.

Table 5.15. Range of starch scores at harvest, storage times, harvest dates and preharvest hours accumulated within which no scald incidence was recorded for ‘Gala’ harvested from Batlow, NSW in 2000 and 2001.

<table>
<thead>
<tr>
<th>Year</th>
<th>Harvest Date</th>
<th>Starch Score</th>
<th>Hours &lt;10°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>23/02/00</td>
<td>2.02</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>1/03/00</td>
<td>3.35</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>8/03/00</td>
<td>4.55</td>
<td>8</td>
</tr>
<tr>
<td>2001</td>
<td>20/02/01</td>
<td>2.95</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>27/02/01</td>
<td>4.3</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>6/03/01</td>
<td>4.8</td>
<td>0</td>
</tr>
</tbody>
</table>

Huonville, Tasmania

Similarly, two years of forecasting trials assessing the scald susceptibility of ‘Gala’ apples harvested from one orchard in Huonville, Tasmania showed that this cultivar is very scald resistant over a wide range of storage times, harvest dates and starch scores at harvest. No scald was recorded in 2000 and 2001 in fruit harvested between 1st March and 21th March with a starch score at harvest ranging between 2.0 and 4.5 (Table 5.16). Storage times studied ranged from four to eight months.

Table 5.16. Range of starch scores at harvest, storage times, harvest dates and preharvest hours accumulated within which no scald incidence was recorded for ‘Gala’ harvested from Huonville, Tasmania in 2000 and 2001.

<table>
<thead>
<tr>
<th>Year</th>
<th>Harvest Date</th>
<th>Starch Score</th>
<th>Hours &lt;10°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1/03/00</td>
<td>2.8</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>8/03/00</td>
<td>3</td>
<td>114</td>
</tr>
<tr>
<td></td>
<td>15/03/00</td>
<td>3.5</td>
<td>146</td>
</tr>
<tr>
<td>2001</td>
<td>7/03/01</td>
<td>2</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td>14/03/01</td>
<td>4</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>21/03/01</td>
<td>4.5</td>
<td>182</td>
</tr>
</tbody>
</table>
5.4 Discussion

Scald prediction at harvest is a complex issue as there are many factors affecting scald susceptibility of apples. These include cultivar, maturity, orchard temperatures, skin colour, nutrient content, fruit size and soil moisture content (Kupferman, 2001). This study has focused on the effects of storage time, orchard temperatures and fruit maturity at harvest in an attempt to develop practical scald prediction models that can be easily used by growers to determine scald susceptibility of apples before CA storage. For many of the cultivar-district combinations studied there is good potential for scald prediction models to be further developed based on scald incidence data already collected. In other cases at least two more years of trials are required before an accurate model can be developed.

It is clear from this study that it is almost impossible to develop accurate prediction models for specific cultivars across more than one district due to differences in weather patterns and production practices. For example the scald incidence data collected for ‘Granny Smith’ in three districts clearly shows that the importance of model predictors in forecasting scald susceptibility vary depending on climatic conditions suggesting that development of a single model for use in both mild and cool districts is not possible. In cooler districts such as Huonville and the Yarra Valley it has been found that accumulated preharvest hours is usually the most significant predictor of scald susceptibility. Many hours below 10°C tend to accumulate over a relatively short period before harvest resulting in lower scald incidence after storage while maturity does not change significantly over the same period. In contrast, fruit maturity generally changed significantly before and during harvest in warmer climates so that starch score was likely to be the important scald predictor. In cases where commercial harvest was relatively late eg. ‘Pink Lady’ in the Goulburn Valley, both preharvest hours and starch score were significant predictors of scald incidence.

The same preliminary fixed model including both linear and quadratic terms of accumulated preharvest hours below 10°C, starch score at harvest and storage time was fitted to scald incidence data on the assumption that a curvilinear relationship exists between these predictors and scald. A sigmoid-type relationship would be expected where at each storage period there would be a starch score or preharvest hour value above which scald susceptibility would remain close to zero (Figure 5.16). On the other hand there would also be predictor values below which scald incidence will be close to 100%.

![Figure 5.16](image-url)  
Figure 5.16  Theoretical relationship between apple scald incidence and scald predictor variables such as starch score at harvest and accumulated preharvest hours.
Between these values scald incidence will decrease with increasing starch score at harvest or preharvest hours and increase with longer storage times. The exact shape of this relationship will depend on the cultivar and climate. In a number of trials it has been difficult to obtain a wide-enough range of predictor values to adequately fit this type of model to the data. For some cultivars and districts the predictor values required are well outside the range of starch scores, preharvest hours and storage times encountered during the harvest period.

Further development of preliminary forecasting models fitted to data collected in this study should allow growers and CA operators to predict scald susceptibility of a batch of fruit fairly accurately. Table 5.17 summarises the significant predictors for each cultivar-district combination for which sufficient data was available to fit a prediction model. Suggested combination of starch scores, storage times and preharvest hours at which scald susceptibility of apples is very low ie. Less than 5% for each cultivar-district combination should be used with care. Ideally growers who intend to utilise these recommendations and models in the future should begin by conducting small storage trials using up to 5 bins of undipped fruit over several seasons. This will enable them to gauge the variation in scald susceptibility of apples grown under local production practices and climatic conditions.

Further development of preliminary models is required before more accurate recommendations can be made. The wide range of predictor values obtained for these cultivars should allow the development of robust and practical prediction models in the near future.

Table 5.17. Summary of important scald predictors determined by fitting a prediction model to data collected over three or more years for each cultivar-district combination.

<table>
<thead>
<tr>
<th>Cultivar-District combination</th>
<th>Significant scald predictors(^A)</th>
<th>Predictor values at which scald incidence estimated to be &lt;5%</th>
<th>DPA rates for fruit with low scald susceptibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Granny Smith’ – Yarra Valley</td>
<td>-Preharvest hours &lt;10°C</td>
<td>Hours10(^B) &gt; 450 and a storage time of up to 5-6 months</td>
<td>Use of no DPA possible</td>
</tr>
<tr>
<td></td>
<td>-Starch score at harvest</td>
<td>Starch score &gt;4.0 and a storage time of up to 4 months</td>
<td>Reduced DPA rates only</td>
</tr>
<tr>
<td></td>
<td>-Storage time</td>
<td>Hours10 &gt; 350 and a storage time of up to 6 months</td>
<td>Use of no DPA possible</td>
</tr>
<tr>
<td>‘Pink Lady’ – Yarra Valley</td>
<td>-Preharvest hours &lt;10°C</td>
<td>Hours10 &gt; 250 and a storage time of up to 6 months</td>
<td>Use of no DPA possible</td>
</tr>
<tr>
<td></td>
<td>-Starch score at harvest</td>
<td>Hours10 &gt; 250 and a storage time of up to 6 months</td>
<td>Use of no DPA possible</td>
</tr>
<tr>
<td></td>
<td>-Storage time</td>
<td>Hours10 &gt; 250, starch score &gt;4.0 and a storage time of up to 6 months</td>
<td>Reduced DPA rates only</td>
</tr>
<tr>
<td>‘Pink Lady’ – Huonville</td>
<td>-Preharvest hours &lt;10°C</td>
<td>Cannot be determined</td>
<td></td>
</tr>
<tr>
<td>‘Red Delicious’ – Yarra Valley</td>
<td>-Preharvest hours &lt;10°C</td>
<td>Cannot be determined</td>
<td></td>
</tr>
</tbody>
</table>

\(^A\) Determined by fitting proposed model to data from each cultivar-district combination.

\(^B\) Hours10 = accumulated preharvest hours below 10°C
For other cultivar-district combinations potentially useful forecasting models can be developed using at least two more years of scald incidence data. These include:

- ‘Pink Lady’ cultivar grown in the Adelaide Hills using starch score at harvest and storage time as predictors.
- ‘Pink Lady’ cultivar grown in Batlow, NSW using starch score at harvest, preharvest hours below 10°C and storage time as predictors.
- ‘Red Delicious’ cultivar grown in low and high elevation regions in Batlow, NSW using starch score at harvest as a predictor.
- *Hi Early* and *Tas Ag8* ‘Red Delicious’ cultivars grown in Huonville, Tasmania using preharvest hours below 10°C as a predictor.
- ‘Fuji’ cultivar grown in Huonville, Tasmania using preharvest hours below 10°C and storage time as predictors.
- ‘Jonagold’ cultivar grown in Huonville, Tasmania using starch score at harvest and storage time as predictors.

Even though six years of scald incidence data was collected for ‘Granny Smith’ grown in the Goulburn Valley in Victoria the potential to predict scald and reduce DPA rates is limited due to the relatively high scald incidence recorded even after short-term CA storage. This is unfortunate, as any reduction in the high DPA rates currently used by growers for this cultivar in this district will have significant cost benefits. More detailed analysis of the relationship between storage time, accumulated preharvest hours above 25°C and scald incidence may allow the development of an appropriate and useful prediction model.

As scald susceptibility decreases, as indicated by prediction models, the DPA concentration necessary to control scald also decreases. The DPA rates necessary to control superficial scald on low susceptibility or scald resistant fruit have not been determined for most cultivars. Weis et al. (2000) have found that for New England-grown ‘Red Delicious’ in the US, 1000-2000 ppm DPA is required to control scald in highly-susceptible fruit. For intermediately susceptible apples 500 ppm DPA is required and less than 250 ppm DPA for scald-resistant fruit as determined by their prediction model for this cultivar. They have also shown that when fruit have accumulated greater than 190 preharvest hours below 10°C the use of DPA is not required. As yet there is little information regarding the use of reduced DPA rates based on the scald susceptibility of a batch of fruit for Australian-grown cultivars. Until this data becomes available a conservative approach will have to be taken by growers when adjusting DPA rates.

There are other considerations when attempting to use a scald forecasting model that will impact on the prediction accuracy and the practicality of using it as part of a commercial operation. Even though some late-harvested fruit that is more mature or exposed to greater accumulated preharvest hours might have lower scald susceptibility than optimum-harvested fruit for CA storage, postponing the harvest cannot usually be justified under commercial practice. Late-harvested fruit for cultivars such as Red Delicious and Granny Smith are usually not suitable for long-term CA storage. Prediction models for these varieties will more than likely be used to forecast scald susceptibility at normal commercial harvest for short-to-medium term CA storage at which point the grower can decide on the most suitable scald control program. Significant quality loss and fruit deterioration did occur in some cultivars such as ‘Pink Lady’ and ‘Granny Smith’ picked later than commercial harvest and stored in CA beyond seven months. Senescent scald, loss of firmness and poor eating quality occurred in fruit harvested past optimum maturity for long-term CA storage.

Another difficulty with using the forecasting approach is that many growers do not know how long a batch of fruit will be stored for at harvest. Market conditions usually determine when a particular cultivar is removed from storage and packed. Furthermore small errors in orchard temperature measurements and the inherent variability of fruit maturity within an orchard can impact on the accuracy of forecasting predictions. For a grower to become confident in using scald forecasting as a practical management tool they would have to have a good idea of the maturity variation within blocks and even within individual trees. Enough fruit would have to be assessed
from each block to get an ‘accurate’ starch score and orchard temperature data obtained from a weather station or shielded temperature loggers in the orchard.

Findings in this project have demonstrated the potential use of scald forecasting as an alternative method of scald control. Many issues still require consideration and future research should focus on:

- Further development and refinement of existing scald forecasting models for Pink Lady, Red Delicious and Granny Smith cultivars.
- Determining the DPA rate reductions possible for specific cultivars based on predicted scald susceptibility at harvest.
- Development of forecasting models for pears based on firmness and preharvest hours eg. Packhams Triumph, particularly for potential use by organic growers.
- Development of a decision-tree/calculator for grower use based on the final models developed for each cultivar in the form of a simple-to-use spreadsheet program.
- Identifying the ‘physiologically’correct threshold temperatures for specific cultivar-district combinations used to determine preharvest hours before harvest.
- Determining the relative importance of preharvest ‘cold’ temperatures and fruit maturity in reducing scald susceptibility for particular cultivars and districts.
- Identifying whether high ambient temperatures reduce scald resistance and by what amount, and if cold weather earlier in the season at low fruit maturity is as effective as it is later in the season in reducing scald susceptibility.

The project findings have been progressively disseminated through articles in various industry publications and, presentation of results and distribution of articles at grower field days and meetings. Extension activities have ensured that a majority of growers in the major pome fruit districts have knowledge of the potential for scald forecasting to reduce chemical use. It is intended to publish a refereed paper based on the findings of this work as well as develop further extension material detailing the practical application of forecasting once accurate predictive models are developed to a stage where they can be confidently used by growers.

The ability to forecast scald susceptibility for a specific cultivar grown in a particular district will enable management decisions to avoid the occurrence of scald. In some cases, forecasting will allow the elimination of DPA dipping or drenching. This could lead to reduced postharvest rot development by avoiding wetting of fruit. If scald susceptibility is found to be low for a certain batch of fruit then the DPA concentration required in dips may be decreased leading to reduced chemical costs for growers and enhanced market fitness for apples through reduction of DPA residues. Current problems with the disposal of used DPA will also be eliminated or reduced, minimising impact on the environment.
6. ULTRA LOW OXYGEN

6.1 Introduction

Controlled atmosphere storage at low levels of oxygen and carbon dioxide reduces the occurrence of scald. Recent evidence shows that ultra low oxygen (ULO) storage at oxygen levels below 1% can give complete scald control for up to 4 months on Granny Smith apples (Ghahramani and Scott 1998; Zanella 2003) and up to 8 months on Red Delicious (Wang and Dilley 2000).

As scald is caused by an oxidation reaction, its occurrence must depend upon the oxygen concentration in the coolstore, with the lower the oxygen the less scald. It is also suspected that ethanol and other volatiles produced by the fruit at low oxygen levels contribute to scald control, although the mode of action is not known.

There is potential for ULO storage to provide very good scald control in some apple cultivars.

6.2 Materials and Methods

6.2.1 Cultivar and Growing Region

In 2000, Red Delicious apples (Red Chief/ Tas Ag 2) were harvested from Batlow, Huonville and three regions within Victoria (the Yarra Valley, Harcourt and Stanley). In 2001 and 2002, Red Delicious were harvested from Batlow and Huonville, and Pink Lady were harvested from the Yarra Valley as this was deemed to be a more important cultivar in Victoria.

Apples from interstate were transported overnight to IHD, Knoxfield, where they were stored.

6.2.2 Experimental design

The fruit was harvested at commercial maturity; the average starch score is presented in Table 6.1. There were 3 replicates (blocks) of each treatment combination. Each block was large enough to harvest three hundred fruit (150 to be stored under ULO and 150 under CA) which was usually one tree, with groups of trees used for lower yielding trees. Within each block, the fruit was placed into 6 bags of 50 fruit.

In storage at 0°C, within each block, there were 2 tubs randomly allocated to either CA (2.5%O₂: 1%CO₂) or ULO. The ULO atmosphere was intended to be (0.7% O₂: 0.5% CO₂), but in most cases the oxygen levels remained at an average of around 1.1%. Within each tub, there were 3 bags of fruit randomly allocated to a storage time of 3, 6, or 9 months.

Fruit was then moved to air storage at 2°C for 5 weeks to simulate holding and shipping conditions. Finally the apples were ripened for one week at 20°C before assessing for scald incidence and quality (firmness, internal browning and background colour for Pink Lady).

Table 6.1 Starch score at harvest of fruit used for ULO storage trials, measured using the 1-5 scale.

<table>
<thead>
<tr>
<th>Year</th>
<th>Batlow</th>
<th>Huonville</th>
<th>Yarra Valley</th>
<th>Stanley</th>
<th>Harcourt</th>
<th>Pink Lady</th>
<th>Yarra Valley</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1.6</td>
<td>1.2</td>
<td>2.7</td>
<td>1.7</td>
<td>-</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>1.3</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>1.5</td>
<td>1.7</td>
<td></td>
<td></td>
<td></td>
<td>2.6</td>
<td></td>
</tr>
</tbody>
</table>
6.2.3 Statistical Analysis

Results were analysed using ANOVA, GenStat for Windows 5th edition (Lawes Agricultural Trust, IACR-Rothamsted) and significance determined using LSD’s at the 5% significance level. The LSD bars presented in the figures are for the comparison of ULO and conventional CA. LSDs for comparing storage duration are not presented.

Where scald occurrence for both treatments was zero the data was removed from the analysis. Where one treatment resulted in zero scald and the other did not results were analysed by Fishers exact test.

6.3 Results

6.3.1 Red Delicious from Batlow

In the 2000 season, ULO treated fruit developed significantly less scald than those stored under conventional CA (Fig 6.1). ULO treated apples showed no scald for up to 6 months while significantly more (19%) of the conventionally stored fruit were scalded (Fisher’s exact test P<0.001). After 9 months storage ULO stored fruit had 8% scald incidence compared to 77% for non-ULO stored.

Scald incidence in 2001 was substantially less than in 2000 for both storage regimes but the ULO fruit still displayed significantly less scald than CA stored. ULO fruit had no scald after 6 months of storage while conventionally stored fruit was beginning to develop a small amount. After 9 months the ULO treated fruit showed significantly less scald (1% compared to 5%).

In 2002 fruit stored for 9 months under ULO developed significantly less scald than fruit stored under conventional CA (Fisher’s exact test P<0.001).

For 2001 and 2002 there was no significant difference in the percent of affected apples for 6 and 9 months storage under ULO. However, fruit stored under conventional CA showed an increase in scald over this time (Fig 6.1).

Fruit stored under ULO appeared to be somewhat firmer after 7 days ripening (Fig 6.2). However, there was found to be no statistically significant difference in firmness due to storage atmosphere.

Some internal browning was found after 9 months storage in 2000 and 2001, but was present in equal amounts in both CA and ULO stored fruit.
Figure 6.1 Incidence of scald on ULO and conventional CA stored Red Delicious from Batlow in 2000-2002. Error bar is LSD (P=0.05) for comparison of ULO and CA.

Figure 6.2 Average Firmness (after 7 days ripening) of ULO and conventionally stored Red Delicious from Batlow in 2000-2002. Error bar is LSD (P=0.05) for comparing ULO and CA.
6.3.2 Red Delicious from Huonville

In the 2000 season, fruit stored under ULO developed no scald during 6 months storage, whereas 9% of CA stored fruit were affected (Fisher’s exact test P<0.001) (Fig 6.3). After 9 months storage the ULO stored fruit had significantly less scald than the conventionally stored fruit, 9% and 66% respectively.

In 2001, Huonville Red Delicious developed no scald in the first 3 months. After 6 and 9 months the ULO stored fruit had significantly less scald than conventionally stored fruit (1% and 13% compared to 13% and 28%)

In 2002, scald incidence was substantially less overall than in previous years. No scald developed in the first 6 months regardless of storage atmosphere. After 9 months the ULO stored fruit still had no scald while the conventionally stored fruit had 2% incidence. (Fig 6.3)

ULO storage also had significant effects on the maintenance of firmness when compared to conventional CA storage in 2000 and 2001. (Fig 6.4).

No internal browning was observed for any of the three years.
Figure 6.3 Incidence of scald on ULO and conventional CA stored Red Delicious from Huonville in 2000-2002. Error bar is LSD (P=0.05) for comparison of ULO and CA.

Figure 6.4 Average firmness (after 7 days ripening) of ULO and conventionally stored Red Delicious from Huonville 2000-2002. Error bar is LSD (P=0.05) for comparing ULO and CA.
6.3.3 **Red Delicious apples from Victoria**

In 2000, Red Delicious were harvested from three areas in Victoria. After six months storage, fruit from the Yarra Valley developed 1% scald in ULO storage and 41% in CA. After nine months this was 11% and 87% respectively (Fig 6.5).

Fruit from Stanley developed no scald until nine months storage, at this time the ULO fruit had significantly less scald and the CA fruit (Fig 6.6).

Apples from Harcourt had a much higher scald incidence overall, but still significantly less under ULO storage especially after the first three months when levels were reduced from 86% to 32% (Fig 6.7).

ULO had no significant effect on firmness of apples from any of the three orchards. Some internal browning was observed at nine months storage for both ULO and CA.

---

**Figure 6.5** Incidence of scald and average firmness of ULO and conventional CA stored Red Delicious from the Yarra Valley. Error bar is LSD (P=0.05) for comparison of ULO and CA.

**Figure 6.6** Incidence of scald and average firmness of ULO and conventional CA stored Red Delicious from Stanley in 2000. Error bar is LSD (P=0.05) for comparison of ULO and CA.

**Figure 6.7** Incidence of scald and average firmness of ULO and conventional CA stored Red Delicious from Harcourt in 2000. Error bar is LSD (P=0.05) for comparison of ULO and CA.
6.3.4 Pink Lady apples from the Yarra Valley

In 2001 and 2002, Pink Lady from the Yarra Valley were stored under ULO and CA. Fruit harvested in the 2001 season developed no scald after 6 months of storage. After 9 months the CA stored fruit had developed 6% scald compared to 3% under ULO storage. No significant difference was found in firmness or background colour due to the storage atmosphere. Some internal browning was observed after 9 months storage, which was not significantly affected by storage atmosphere. Some slight alcoholic off flavours were apparent in the fruit stored for 6 months.

Fruit harvested in the 2002 season and stored under ULO developed significantly less scald than CA stored fruit for all storage lengths (Fig 6.8). In general, scald was much more severe than in the 2001 season. ULO fruit were greener than CA stored fruit after 6 and 9 months storage (Fig 6.9) but there was no significant improvement in firmness. No off flavours were observed this season. There was a high incidence of internal browning under all treatments.

Figure 6.8 Incidence of scald on ULO and conventional CA stored Pink Lady from the Yarra Valley in 2002. Error bar is LSD (P=0.05) for comparison of ULO and CA.

Figure 6.9 Average background colour (after 7 days ripening) of ULO and conventionally stored Pink Lady from the Yarra Valley in 2002. Error bar is LSD (P=0.05) for comparing ULO and CA.
Figure 6.10 Pink Lady apples harvested from the Yarra Valley in 2002 and stored for 6 months. The fruit on the left was stored under ULO while the fruit on the right was stored under conventional CA.

6.4 Discussion

Ultra Low Oxygen storage effectively prevented development of superficial scald on both Red Delicious and Pink Lady fruit stored up to 6 months. The treatment may also increase the storage life of the fruit in some cases by delaying softening.

In general, no detrimental effects on fruit quality due to ULO storage were observed. Previous research found that ULO may cause alcoholic taints or skin browning. This was not apparent for the Red Delicious in this study, but was sometimes found in the Pink Lady. It is possible that the 5 weeks storage in air after ULO storage allowed any alcoholic tainting to dissipate. In some cases a small amount of internal browning was observed in the 9 months stored fruit but this was not related to storage atmosphere.

For longer-term storage, ULO could enable scald control using lower rates of DPA. Unlike DPA, ULO would be accepted by all markets including organic fruit production. Because this treatment bypasses the drenching/dipping procedure the transfer of pathogens is avoided and it may therefore be possible to avoid using postharvest fungicides.

As efficient ULO requires rooms to be well sealed, it would not be feasible in many existing stores. It is not possible to generalise on the cost benefit of ULO compared with conventional CA. The costs of constructing new stores and effectively sealing existing stores together with any increase in equipment and running costs will need to be calculated for individual farms.
7. 1-METHYLICYCLOPROPENE

7.1 Introduction

1-Methylcyclopropene (1-MCP) is an ethylene action inhibitor that has been studied for some time in relation to storage life of cut flowers (Sisler and Serek 1997) as well as fruit and vegetables. It has been shown to improve the storage life of ethylene sensitive produce such as apples by delaying ripening (Fan et al. 1999).

It works by permanently binding to the ethylene receptors so any ethylene mediated reactions cannot proceed (Sisler and Serek 1997). After some time new receptor sites are manufactured allowing the return of ethylene action and therefore normal ripening and senescence.

Apart from delaying ripening it has also been shown to provide very good control of superficial scald at very low concentrations. Ethylene plays a part in regulating \( \alpha \)-farnesene biosynthesis during fruit ripening and there are correlations between increasing internal ethylene and \( \alpha \)-farnesene production (Ju and Curry 2000). As well as inhibiting ethylene action 1-MCP is reported to delay or reduce the accumulation of \( \alpha \)-farnesene and its oxidation products (Watkins et al. 2000). This would therefore lead to a delay in scald development.

1-MCP has recently been registered for use on apples and pears in the United States and registration in Australia is expected. Treatment is effective at very low concentrations, and there are no detectable residues, according to the manufacturers, Rohm and Hass, analyses in 2000.

Three trials were conducted during this project to test the efficiency of 1-MCP for Scald control. Granny Smith apples were tested during 2001 and 2002, and Red Delicious during 2002.
7.2 Effect of 1-MCP on Granny Smith apples - 2001 Season

During the 2001 season the effect of 1-MCP on scald development and storage life was investigated on Granny Smith apples. Fruit was harvested from the Goulburn Valley at commercial maturity and treated with 10,000 ppb 1-MCP followed by storage under controlled atmosphere at 0°C for 8 months.

Treated fruit developed no superficial scald and were significantly greener and firmer than untreated apples.
Effect of SmartFresh on superficial scald and the storage life of Granny Smith apples. Part 1.

Supplement to Final Report
Horticulture Australia
Project AP 99010

Ian Wilkinson, Simone Kreidl, Robert Holmes, Christine Frisina, Peter Franz
Effect of SmartFresh [a.i. 1-methylcyclopropene (1-MCP)] to prevent superficial scald the storage-life of Granny Smith apples.

Supplement to Final Report for Project AP 99010

Principal investigator:
Robert Holmes
Agriculture Victoria
Institute for Horticultural Development
Private Bag 15
Ferntree Gully Delivery Centre Vic 3156 AUSTRALIA

☎ (03) 9210 9222
Fax (03) 9800 3521
e-✉ robert.holmes@nre.vic.gov.au

Purpose of the report:
This project (AP 99010) was directed towards:

1. Determine the effect of SmartFresh (1-methylcyclopropene) on superficial scald.
2. Determine the benefits of SmartFresh on the storage life of Granny Smith apples.

Funded by:
Horticulture Australia Ltd and Rohm and Haas P/L

Text by:
Ian Wilkinson

Date of report:
December 2001


Disclaimer
Any recommendations contained in this publication do not necessarily represent current HAL policy. No person should act on the basis of the contents of this publication, whether as to matters of fact or opinion or other content, without first obtaining specific, independent professional advice in respect of the matters set out in this publication
CONTENTS

SUMMARY .................................................................................................................................................. 66
INTRODUCTION ........................................................................................................................................... 67
2. MATERIALS AND METHODS .................................................................................................................. 67
3. RESULTS ................................................................................................................................................ 70
4. DISCUSSION AND CONCLUSIONS .................................................................................................... 71
5. RECOMMENDATIONS .......................................................................................................................... 72
6. REFERENCES .......................................................................................................................................... 72
7. TABLES .................................................................................................................................................. 73
8. PLATES .................................................................................................................................................. 75
SUMMARY

SmartFresh [a.i. 3.3% 1-methylcyclopropene (1-MCP)] blocks the action of ethylene in fruit when applied as a post harvest fumigation treatment at very low concentrations in the parts per billion (ppb = µl/l) range. In this study SmartFresh was applied to Granny Smith apples at a concentration of 10,000 ppb at 20°C for 23 hours, approximately 8 hours after harvest.

SmartFresh prevented superficial scald development in Granny Smith apples after 8 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1% CO₂) followed by 7 days at 20°C. The fruit treated with SmartFresh were significantly greener, firmer and had fewer rots compared with non-SmartFresh (control) treated fruit. SmartFresh had no significant effect on the total soluble solids levels of the fruit. SmartFresh had no significant effect on the incidence of sun-scald but did reduce the severity of the disorder compared to non-SmartFresh treated fruit.

The incidence (13.3%) and slight severity rating of superficial scald development on the non-SmartFresh treated fruit was much lower than was anticipated. Fruit picked 3 days later from the same block of trees as was used for the SmartFresh experiment, had severe superficial scald after 5 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1% CO₂) plus 7 days at 20°C. The SmartFresh treated and not treated (control) fruit were stored together in 150 litre controlled atmosphere chambers. Therefore, the failure to observe severe superficial scald on the non-SmartFresh control fruit may be attributed to the volatile transfer of 1-MCP from treated to control fruit during storage.

The industry representatives that have seen the results of this SmartFresh study are keen for the work to continue. Ideally, they would like to be able to store SmartFresh treated fruit for 12 months which is not achievable with the use of DPA. Potentially, ultra low oxygen storage could achieve 12 months storage but scald control would not be 100%, the technology is expensive, costly to run and many commercial cool rooms are not capable of maintaining a 0.7% to 1.5% oxygen atmosphere.

The growers need assurances that 1-MCP is safe to use and is not going to be expensive.

SmartFresh has the potential to control superficial scald in Granny Smith apples. However, further trials are needed to determine the optimum concentration of SmartFresh and its interaction with harvest maturity and storage duration. Work is also needed on a commercial scale in developing practical delivery methods for SmartFresh.
INTRODUCTION

At the National Scald project meeting held at IHD, Knoxfield on 23rd January 2001, there was full support from all members present for investigating the potential for SmartFresh to control scald. In general, the results of the ultra low oxygen storage trial 2000 showed the incidence of superficial scald in Red Delicious apples could be reduced to less than 5% after 6 months storage in a 0.7% oxygen atmosphere. However, fruit stored in 2.5% oxygen atmosphere had unacceptable levels of superficial scald (greater than 10%). The growers are seeking 100% scald control. SmartFresh has been reported overseas to give 100% scald control in air for 3 months. There may be significant synergistic benefits of using SmartFresh and standard oxygen storage (2.5%) rather than having to store the fruit at 0.7% oxygen. There are significant energy cost savings in being able to store fruit at 2.5% as against 0.7% and there is less risk of low oxygen injury. We used the apple variety Granny Smith for the SmartFresh experiment as it is highly susceptible to scald and it is being studied in the National scald project.

1. EXPERIMENTAL OBJECTIVES

1. Determine the effect of SmartFresh (1-methylcyclopropene) on superficial scald.
2. Determine the benefits of SmartFresh on the storage life of Granny Smith apples.

2. MATERIALS AND METHODS

Handling, fumigation and storage

Handling

Granny Smith apples 90 count were harvested from the Shepparton growing region in Victoria on the morning of 15th March 2001, and transported to IHD, Knoxfield the same day. Initial pre-storage quality measurements were conducted. These were flesh firmness, using an 11mm penetrometer, measured as kilograms force (kgf), total soluble solids (TSS) measured in °Brix and skin colour measured as hue angle (h°).

Fumigation

On arrival at IHD, the fruit was sorted, placed into netting bags and labelled according to the required treatments. Thirty fruit were allocated per bag. The bags were placed into each 150L fumigation chamber. The non-SmartFresh treated fruit were placed in fumigation chamber but received no 1-MCP. Fumigation took place at 8 hours after harvest and consisted of six blocks of each treatment (0ppb, and 10000ppb). Each fumigation chamber also contained an open tray of 20% potassium hydroxide (50ml) to absorb carbon dioxide. Vials containing SmartFresh powder were taped to the inside of the chambers perspex lids and warm water (rate 16 ml to 1 gram SmartFresh) injected into individual vials to initiate fumigation within the chamber. The fumigation period lasted 23 hours at 20°C.

Storage

Non-SmartFresh (control) and SmartFresh treated fruit were stored together in replicated CA chambers. The fruit were placed into controlled atmosphere (2.5% O₂ / 1.0% CO₂) storage at 0°C for 32 weeks. All fruit were held at 20°C for seven days prior to assessment.
Measurements and assessments

Temperature

Ambient air temperature was monitored continuously during the storage period and was maintained within ±0.5°C of the set point.

Atmosphere

Carbon dioxide and oxygen levels inside the CA chambers were monitored and controlled by a Bishop Instrument gas analyser.

Quality

(a) Quality assessments: Firmness (kgf), skin colour (hue angle: \( h^\circ \)), total soluble solids (°Brix), incidence and severity for superficial scald and sun-scald.

The severity rating scale for superficial scald standard plates:

1 = none  2 = trace  3 = slight  4 = moderate  5 = severe

The severity rating scale for sun-scald standard plates:

1 = none  2 = trace  3 = slight  4 = moderate  5 = severe

The fruit quality assessments were done on a sample of 30 fruit at harvest prior to the SmartFresh treatment and after 32 weeks plus 7 days at 20°C.

Fruit from each experiment were compared with respect to skin colour, firmness and total soluble solids (TSS) content.

Skin colour was measured using a Minolta CR200 chromameter using the white calibration tile (\( L= 97.3, a= -0.49, b= 1.91 \)). The b-values and a-values measured by the chromameter were used to calculate the hue angle values. The hue angle is used to determine the changes in ground colour greenness. Hue angle (\( h^\circ \)) = arc(tangent \( b/a \)) where 90° = yellow and 180° = green, consequently, high \( h^\circ \) values indicate greener fruit. A hue angle value of 110 \( h^\circ \) represents green and 105 \( h^\circ \) represents green / yellow. Relatively small changes in \( h^\circ \) can represent a substantial visual change in the colour from green to yellow.
Flesh firmness, expressed as kilogram force (kgf) was measured using a penetrometer with an 11 mm. plunger.

Total soluble solids (TSS) content, expressed as °Brix, was measured using a digital refractometer.

Starch-iodine rating scale used for scoring Granny Smith apples maturity at harvest.

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

_Design:_

2 SmartFresh treatments x 6 blocks x 30 fruit per block.

_Treatments:_ SmartFresh at 0 ppb and 10000 ppb.

_Blocks:_ 6

_Statistical Analysis_

The data was analysed by analysis of variance (ANOVA) using Genstat version 5.4. 2 software.

3. RESULTS

_Superficial scald_  
The incidence of superficial scald for Granny Smith apples after 32 weeks at 0°C in CA storage treated with SmartFresh was zero compared to non-SmartFresh treated fruit with 13.3% (Table 1, Plate 3). The severity of the superficial scald for non-SmartFresh treated fruit averaged at the trace level. Note fruit was observed with slight and moderate severity levels of scald in non-SmartFresh treated fruit.

_Sunburn scald_  
The incidence of sun-scald for Granny Smith apples after 32 weeks at 0°C in CA storage treated with SmartFresh was not significantly different compared with non-SmartFresh treated being 29.8% and 35.2% respectively (Table 2). The severity of sun-scald for SmartFresh treated fruit was significantly less compared to fruit not treated with SmartFresh being rated as a trace to slight severity for SmartFresh treated fruit and slight severity for fruit not treated with SmartFresh.

_Skin Colour_  
The fruit was picked mature green skin colour (Plate 1). The mean skin colour of the fruit on arrival at IHD was 116.5 h°.  
The skin colour of Granny Smith apples after 32 weeks CA storage treated with SmartFresh were significantly greener compared with non-SmartFresh treated being 118.7 h° and 117.8 h° respectively (Table 3).

_Iodine starch rating_  
The iodine starch rating of Granny Smith apples at harvest averaged 3.7 on the 10 point scale (Plate 2).

_Firmness_  
The mean of Granny Smith apples on arrival at IHD, Knoxfield averaged 8.0 kgf on 30 fruit. The firmness of Granny Smith apples after 32 weeks at 0°C in CA storage treated with SmartFresh were significantly firmer compared with non-SmartFresh fruit being 7.9 kgf and 7.7 kgf respectively (Table 4).

_Total soluble solids_  
The average total soluble solids (°Brix) of Granny Smith apples was 11.1 °Brix (n=30 fruit). The total soluble solids (°Brix) of Granny Smith apples after 32 weeks at 0°C in CA storage treated with SmartFresh were not significantly different compared with non-SmartFresh treated fruit being 12.6°Brix (Table 5).
Incidence of rots

The incidence of storage rots in Granny Smith apples after 32 weeks at 0°C in CA storage treated with SmartFresh were significantly less compared with non-SmartFresh treated fruit being 1.7% and 5.6% respectively (Table 6).

4. DISCUSSION AND CONCLUSIONS

Currently, superficial scald is controlled by drenching apples with extremely high concentrations (500 to 4000 ppm) of an antioxidant, DPA. However, future use of DPA is under scrutiny because of its possible undesirable effects on human health. Recent survey results of DPA residue levels on apples in Australia have found some fruit with unacceptably high DPA residue levels. Many major export markets now monitor chemical residue levels very closely and will reject consignments if they exceed the set standard. DPA does not provide 12 months control of scald. The apple industry is in need of an alternative scald control method to DPA that will enable the fruit to be stored for 12 months, with 100% control.

The causes of scald development in apples is complicated, however, the accumulation of \( \alpha \)-farnesene and its breakdown into compounds toxic to the skin cells is believed to cause this disorder. 1-MCP is reported to delay or reduce the accumulation of \( \alpha \)-farnesene and its breakdown toxic compounds (Fan-XueTong, *et al.* 1999, Watkins, *et al.* 2000 and Rupasinghe, *et al.*, 2001). 1-MCP treated apples have been stored in air and CA for 6 months with complete scald control (EthylBloc technical manual, 1999 and Fan-XueTong, *et al.* 1999). Other reports record reduced levels of scald from 1% to 10% (Watkins, *et al.* 2000 and Rupasinghe, *et al.*, 2001). For 1-MCP to be successful the scald control needs to be in the range 95% to 100%.

Watkins, *et al.* 2000 and Rupasinghe, *et al.*, 2001 reported no scald development for fruit stored in controlled atmosphere storage atmosphere 2% oxygen ± 0.5%. Low oxygen storage atmosphere 0.7% to 1.5% can be used to control superficial scald. Therefore, the failure to detect scald is most probably the result of the low oxygen suppression of \( \alpha \)-farnesene and its breakdown toxic compounds.

In this study Granny Smith apples not treated with SmartFresh after 8 months at 0°C in controlled atmosphere storage (2.5% \( O_2 \) plus 1% \( CO_2 \)) and 7 days at 20°C did develop scald but at a much lower level than was anticipated. In a separate experiment Granny Smith apples were picked from the same trees as was used for the SmartFresh experiment, 3 days later and were stored in controlled atmosphere storage (2.5% \( O_2 \) plus 1% \( CO_2 \)) for 5 months at 0°C plus 7 days at 20°C and the fruit developed severe scald (Plate 4). The 2001 season was a bad year for scald development. Therefore, given the similarity of the fruit maturity at harvest and storage atmospheres, it would seem that while low oxygen storage atmosphere would have reduced the incidence and severity of scald it is not the full answer. Therefore, the failure to observe severe superficial scald on the non-SmartFresh control fruit may be attributed to 1-MCP being released from the SmartFresh treated fruit (10000 ppb concentration) during CA storage, which was absorbed by the fruit not treated with SmartFresh. Future experiments should isolate the treated and non-treated fruit to avoid the possibility of 1-MCP coming into contact with control fruit. Also control on the untreated fruit, due to volatile transfer, would indicate the fumigation dose of 1-MCP was probably excessive.

SmartFresh did not effect the sun-scald development. DPA also does not effect sun-scald development but it can in some cases cause sun-scald regions of the fruit to turn black making the fruit unsaleable. No blackening problems were observed on the SmartFresh treated fruit when it was fumigated with 10000 ppb 1-MCP, which is a very high concentration compared to most reported experiments which use 1000 ppb. Therefore, 1-MCP may not cause the blackening problem.
The fruit was picked at mid-harvest maturity i.e. the fruit had a starch iodine pattern midway between optimum and late pick for long term CA storage and the fruit had a good green skin colour.

Late picked fruit with yellow-green skin colour are less prone to superficial scald development. The fruit was picked appropriately for the opportunity for scald to develop. Early picked fruit would be more susceptible to scald development and therefore future studies should test 1-MCP on the earlier picked and mid-picked maturity fruit.

SmartFresh improved the outturn quality of Granny Smith apples. However, the effect of SmartFresh on the eating quality of Granny Smith apples after long term storage needs to be determined.

5. RECOMMENDATIONS

Further work is needed to:

- Determine the optimum concentration of SmartFresh for control of superficial scald and its interaction with harvest maturity and storage duration.
- Develop practical delivery methods for SmartFresh on a commercial scale.
- Determine the effect of SmartFresh on the eating quality.
- Determine the efficacy of SmartFresh against superficial scald and quality parameters on pears.

6. REFERENCES

EthylBloc 1-Methylcyclopropene (1-MCP) Technical Bulletin available from Rohm and Haas P/L.


7. TABLES

**Table 1.** Effect of SmartFresh fumigation at 10,000 ppb for 23 hours at 20°C on the incidence and severity of superficial scald in Granny Smith apples after 32 weeks at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh concentration (parts per billion)</th>
<th>Superficial scald incidence (%)</th>
<th>Superficial scald severity³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppb</td>
<td>13.3</td>
<td>1.9</td>
</tr>
<tr>
<td>10000 ppb</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>LSD¹ (P=0.05)</td>
<td>N.S.A.R.²</td>
<td>N.S.A.R.</td>
</tr>
</tbody>
</table>

¹ LSD = Least significant differences at the 5% level of probability.
² N.S.A.R. = No statistical analysis required.
³ Severity rating scale: 1 = none, 2 = trace, 3 = slight, 4 = moderate and 5 = severe.

**Table 2.** Effect of SmartFresh fumigation at 10,000 ppb for 23 hours at 20°C on the incidence and severity of sun-scald in Granny Smith apples after 32 weeks at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh concentration (parts per billion)</th>
<th>Sun-scald incidence (%)</th>
<th>Sun-scald severity²</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppb</td>
<td>29.8</td>
<td>3.0</td>
</tr>
<tr>
<td>10000 ppb</td>
<td>35.2</td>
<td>2.6</td>
</tr>
<tr>
<td>LSD¹ (P=0.05)</td>
<td>13.8</td>
<td>0.3</td>
</tr>
</tbody>
</table>

¹ LSD = Least significant differences at the 5% level of probability.
² Severity rating scale: 1 = none, 2 = trace, 3 = slight, 4 = moderate and 5 = severe.

**Table 3.** Effect of SmartFresh fumigation at 10,000 ppb for 23 hours at 20°C on ground colour of Granny Smith apples after 32 weeks at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh concentration (parts per billion)</th>
<th>Ground colour (hue angle = h°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppb</td>
<td>117.8</td>
</tr>
<tr>
<td>10000 ppb</td>
<td>118.7</td>
</tr>
<tr>
<td>LSD¹ (P=0.05)</td>
<td>0.6</td>
</tr>
</tbody>
</table>

¹ LSD = Least significant differences at the 5% level of probability.

**Table 4.** Effect of SmartFresh fumigation at 10,000 ppb for 23 hours at 20°C on firmness of Granny Smith apples after 32 weeks at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh concentration (parts per billion)</th>
<th>Firmness (kgf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppb</td>
<td>7.7</td>
</tr>
<tr>
<td>10000 ppb</td>
<td>7.9</td>
</tr>
<tr>
<td>LSD¹ (P=0.05)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

¹ LSD = Least significant differences at the 5% level of probability.
Table 5. Effect of SmartFresh fumigation at 10,000 ppb for 23 hours at 20°C on total soluble solids of Granny Smith apples after 32 weeks at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh concentration (parts per billion)</th>
<th>Total soluble solids (°Brix)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppb</td>
<td>12.6</td>
</tr>
<tr>
<td>10000 ppb</td>
<td>12.6</td>
</tr>
</tbody>
</table>

LSD₁ (P=0.05) 0.4

₁. LSD = Least significant differences at the 5% level of probability.

Table 6. Effect of SmartFresh fumigation at 10,000 ppb for 23 hours at 20°C on the incidence of storage rots of Granny Smith apples after 32 weeks at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh concentration (parts per billion)</th>
<th>Incidence of storage rots (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppb</td>
<td>5.6</td>
</tr>
<tr>
<td>10000 ppb</td>
<td>1.7</td>
</tr>
</tbody>
</table>

LSD₁ (P=0.05) 3.5

₁. LSD = Least significant differences at the 5% level of probability.
8. PLATES

Plate 1. Shows Granny Smith apples taken on the day the fruit was fumigated and shows the fruit had a mature green skin colour.

Plate 2. Shows the iodine starch patterns for Granny Smith apples taken on the day the fruit was fumigated.
Plate 3. Show Granny Smith apples not treated with SmartFresh with superficial scald after 8 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) (left) compared to fruit treated with SmartFresh (10,000 ppb for 23 hours at 20°C) with no scald (right).

Plate 4. Show Granny Smith apples with severe superficial scald after 5 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂). The fruit was from the same block of trees used for the SmartFresh experiment, picked 3 days later and was not treated with SmartFresh.
7.3 Effect of 1-MCP on Granny Smith apples - 2002 Season

During the 2002 season the effect of 1-MCP on scald development and storage life was investigated on Granny Smith apples. Fruit of three different maturities were harvested from the Goulburn Valley and treated with 1-MCP at 625 ppb followed by storage under controlled atmosphere at 0°C for 8.5 and 11 months.
Effect of SmartFresh on superficial scald and the storage life of Granny Smith apples. Part 2.

Supplement to Final Report
Horticulture Australia
Project AP 99010

Ian Wilkinson, Simone Kreidl, Robert Holmes, Christine Frisina, Peter Franz
Effect of SmartFresh on superficial scald and the storage life of Granny Smith apples.

Supplement to Final Report for Project AP 99010

Principal investigator:
Robert Holmes
Agriculture Victoria
Institute for Horticultural Development
Private Bag 15
Ferntree Gully Delivery Centre Vic 3156 AUSTRALIA

☎ (03) 9210 9222
Fax (03) 9800 3521
e-✉ robert.holmes@nre.vic.gov.au

Purpose of the report:
This project (AP 99010) was directed towards:

1. Determine the effect of SmartFresh (1-methylcyclopropene) on superficial scald.
2. Determine the benefits of SmartFresh on the storage life of Granny Smith apples.

Funded by:
Horticulture Australia Ltd and Rohm and Haas P/L and Department of Primary Industries, Victoria.

Text by:
Ian Wilkinson

Date of report:
March 2003


Disclaimer
Any recommendations contained in this publication do not necessarily represent current HAL policy. No person should act on the basis of the contents of this publication, whether as to matters of fact or opinion or other content, without first obtaining specific, independent professional advice in respect of the matters set out in this publication.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUMMARY</td>
<td>81</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>82</td>
</tr>
<tr>
<td>2. MATERIALS AND METHODS</td>
<td>82</td>
</tr>
<tr>
<td>3. RESULTS</td>
<td>86</td>
</tr>
<tr>
<td>4. DISCUSSION AND CONCLUSIONS</td>
<td>88</td>
</tr>
<tr>
<td>5. RECOMMENDATIONS</td>
<td>89</td>
</tr>
<tr>
<td>6. REFERENCES</td>
<td>89</td>
</tr>
<tr>
<td>7. TABLES</td>
<td>90</td>
</tr>
</tbody>
</table>
SUMMARY

SmartFresh [a.i. 3.3% 1-methylcyclopropene (1-MCP)] blocks the action of ethylene in fruit when applied as a post harvest fumigation treatment at very low concentrations in the parts per billion (ppb = µl / l). In this study SmartFresh was applied to Granny Smith apples at a concentration of 625ppb at 20°C for 24 hours, approximately 8 hours after harvest.

The industry representatives that have seen the results of the 2001 SmartFresh trial were keen for the work to continue. Ideally, they would like to be able to store SmartFresh treated Granny Smith apples for 12 months which is not reliably achieved with the use of DPA.

SmartFresh dramatically reduced superficial scald development in Granny Smith apples to 0% to 1.8% when assessed after 8 months and 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1% CO₂) followed by 7 days at 20°C. In addition, the fruit treated with SmartFresh were significantly greener and firmer compared to non-SmartFresh treated fruit. There was no significant effect of SmartFresh on the total soluble solids (TSS) levels at 8 months but after 11 months the TSS for SmartFresh treated fruit was significantly higher compared to non-SmartFresh treated fruit. After 11 months, core flush incidence and severity was significantly reduced in SmartFresh treated fruit compared with non-SmartFresh (control) treated fruit. The severity of the core flush in non-SmartFresh treated fruit meant the fruit was unsaleable compared to the low degree of severity in SmartFresh treated fruit which were saleable. SmartFresh had no significant effect on the incidence of rots or sun-burn scald.

The severity and incidence of superficial scald generally decreases with successive harvests. Therefore, it was important in this trial to harvest fruit over a range of maturities to demonstrate the effectiveness of SmartFresh. The fruit was picked three times within a month. The first pick was very early, second pick was close to optimum physiological maturity for long term CA storage and the third pick was late. After 8.5 months storage the incidence of superficial scald in non-SmartFresh treated fruit was least in the earliest picked fruit and significantly increased with each harvest. This finding appears to contradict the normal relationship between harvest maturity and scald susceptibility. However, several experiments in this project (AP 99010) have demonstrated that in Granny Smith, at least, that very early harvests develop less scald than later harvests. After 11 months there was no significant difference in the incidence and severity of superficial scald for each harvest. Non-SmartFresh treated fruit were not saleable whereas the SmartFresh treated could be sold.

This trial has shown that SmartFresh can control superficial scald in Granny Smith apples. Based on the quality measurements used, the fruit could be stored for 11 months ensuring high quality fruit almost all year round. However, further trials are needed to determine the effect of SmartFresh on eating quality and consumer acceptance of fruit. In addition, commercial trials need to be conducted. This work could be done when SmartFresh has been registered for use on apples in Australia.
INTRODUCTION

Superficial scald is a serious physiological disorder of Granny Smith apples, which is currently controlled by the post-harvest application of the anti-oxidant diphenylamine (DPA). There are increasing concerns about the continued use of DPA and mainly export markets do not permit residues of DPA in the fruit. In addition, DPA does not provide complete protection for long term storage. SmartFresh [a.i. 3.3% 1-methylcyclopropene (1-MCP)] at 1000 ppb prevents superficial scald in Granny Smith apples stored in air or controlled atmosphere storage for 6 months (Mattheis and Fan, 2001 and Zanella, 2003). Wilkinson et.al., 2001 reported that SmartFresh at 10,000 ppb prevented superficial scald for 8 months. The 10,000 ppb concentration was excessive and new experiments were conducted to evaluate a commercially acceptable concentration. SmartFresh is registered in the USA for use on apples using the concentration of 625 ppb. Therefore, Granny Smith apples were treated in 2002 with a concentration of 625 ppb.

As maturity has an influence on scald susceptibility trials in 2002 / 2003 tested 1-MCP on early, middle and late harvest maturity fruit.

DPA does not provide 12 months control of scald on highly susceptible Granny Smith apples. The apple industry is in need of an alternative scald control method to DPA that will enable the fruit to be stored for at least 11 months, with 100% control. Therefore, the Granny Smith apples were assessed after 8.5 and 11 months CA storage.

The purpose of this work is to determine the effect of SmartFresh and its interaction with harvest maturity and storage duration on the post-storage quality and control of superficial scald in Granny Smith apples.

1. EXPERIMENTAL OBJECTIVES

1. Determine the effect of SmartFresh (1-methylcyclopropene) on superficial scald.
2. Determine the benefits of SmartFresh on the storage life of Granny Smith apples.

2. MATERIALS AND METHODS

• Handling, fumigation and storage

Handling

Granny Smith apples 90 count were harvested from the Shepparton growing region in Victoria on the mornings of 28th February, 14th March and 27th March 2002, and transported to IHD, Knoxfield the same day.

SmartFresh treatment

On arrival at IHD, the fruit was sorted, placed into netting bags and labelled according to the required treatments. Thirty fruit were allocated per bag. The bags were placed into each 150L fumigation chamber. The non-SmartFresh treated fruit were placed in fumigation chamber but received no 1-MCP. Fumigation took place 8 hours after harvest and consisted of six blocks of each treatment (0 ppb, and 625 ppb). Each fumigation chamber also contained an open tray of 20% potassium hydroxide (50ml) to absorb carbon dioxide. The fruit was treated with SmartFresh (3.3% active ingredient 1-MCP) for 24 hours at 20°C. A 20,000,000 ppb concentrate was prepared and a gas sample was withdrawn by a syringe and injected into the treatment chamber to deliver 625 ppb. When the SmartFresh treatment was complete all apples were cooled to 0°C.
Storage
Non-SmartFresh (control) and SmartFresh treated fruit were stored in separate replicated CA chambers. The fruit were placed into controlled atmosphere (2.5% O₂ / 1.0% CO₂) storage at 0°C for 8.5 months and 11 months. After storage fruit were held at 20°C for seven days prior to assessment.

Measurements and assessments

Temperature
Ambient air temperature was monitored continuously during the storage period and was maintained within ±0.5°C of the set point.

Atmosphere
Carbon dioxide and oxygen levels inside the CA chambers were monitored and controlled by a Bishop Instrument gas analyser.

Quality
a) Quality assessments: Firmness (kgf), skin colour (hue angle: h°), total soluble solids (°Brix), incidence of sun scald and rots and incidence and severity of superficial scald and internal browning and core flush.

The fruit quality assessments were done at harvest prior to the SmartFresh treatment and after 8.5 months or 11 months plus 7 days at 20°C. Thirty fruit samples were used for the scald, internal browning and core flush assessments and 15 fruit for skin colour, firmness and total soluble solids (TSS) content.

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

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

Total soluble solids (TSS) content, expressed as °Brix, was measured using a digital refractometer.

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

The severity of superficial scald was rated against the following standard plates:

1= none  2 = trace  3 = slight  4 = moderate  5 = severe
Internal browning and core flush was assessed on an incidence basis and recorded as a percentage of fruit affected.

The severity of internal browning was rated against the following standard plates:

![Rating plates for internal browning](image)

The severity of core flush was rated against the following standard plates:
Starch-iodine rating scale used for scoring the maturity of Granny Smith apples at harvest.

**Experimental design and statistical analysis**

Treatments:

- SmartFresh concentrations: 0 ppb and 625 ppb (parts per billion)
- Harvest dates: 28th February, 14th March and 27th March
- Storage times: 8.5 months and 11 months
- Replication: 6

This is a three-phase design with a field phase, SmartFresh treatment phase followed by a storage phase. There were 6 replicates of each treatment combination. In the field, there were 6 blocks (replicates) of trees from which at each harvest date 4 bags of 30 fruit were picked. In the SmartFresh treatment phase, at each harvest within each of the 6 blocks, the 4 bags from the field were allocated to 2 tubs containing 2 bags. The 2 SmartFresh concentrations were randomised to the 2 tubs within each block. In the storage phase, the bags of fruit in the 12 tubs were moved into the 6 blocks of 2 storage tubs in the storage room. After all 3 harvests were treated; each storage tub contained 6 bags of fruit for the 2 storage times by 3 harvest dates randomly positioned within each tub.
3. RESULTS

Superficial scald incidence

SmartFresh significantly reduced the incidence of scald compared to non-SmartFresh treated fruit after 8.5 months and 11 months CA storage at 0°C (Table 1, Plate 1). After 8.5 months the non-SmartFresh treated fruit were not marketable compared to the SmartFresh treated fruit, which were marketable after 11 months storage. SmartFresh gave complete protection against superficial scald after 8.5 months for fruit picked on 28th February and the 14th March and after 11 months on the 14th March and 27th March. However, superficial scald was observed after 8.5 months on fruit picked on the 27th March affecting 1.7% of the fruit and after 11 months on fruit picked on the 28th February affecting 1.8% of the fruit.

The incidence of superficial scald in non-SmartFresh treated fruit after 8.5 months storage increased significantly with each harvest date being 46.4%, 75.6% and 88.7% first pick to last respectively (Table 1). After 11 months there was a significant difference in the incidence of superficial scald between the first harvest date 77.2% compared to the other two dates 97.8% and 96.7% respectively.

No severity data was recorded for 8.5 months storage. The severity of superficial scald after 11 months storage was unacceptable for non-SmartFresh treated fruit and acceptable for SmartFresh treated fruit (Table 2).

Sun scald

SmartFresh had no significant effect on the incidence of sun scald compared to non-SmartFresh treated fruit after 8.5 months or 11 months storage (Table 3, Plate 2).

Iodine starch rating

The average iodine starch rating using the 10 point scale for Granny Smith apples harvested on the 28th February = 2.2, 14th March = 2.7 and 27th March = 4.7 (Plate 3). The starch index at harvest for long term CA storage should be 2.5 to 4 using the 10 point scale (Chennell, et. al., 2002).

Firmness

The average firmness of Granny Smith apples on arrival at IHD, Knoxfield harvested on the 28th February = 8.0 kgf, 14th March = 8.1 kgf and 27th March = 7.7 kgf. The firmness at harvest for long term CA storage should be greater than 6.5 kgf and ideally greater than 8 kgf (Chennell, et. al., 2002, Little and Holmes, 2000). The firmness of Granny Smith apples treated with SmartFresh was significantly firmer compared with non-SmartFresh treated fruit when assessed after 8.5 months and 11 months storage (Table 4).

SmartFresh treated fruit after 11 months storage had effectively the same firmness as measured at harvest. Untreated fruit softened in storage and the fruit was saleable (Table 4).

Total soluble solids

The average total soluble solids (°Brix) of Granny Smith apples at the 3 harvested were: 28th February = 11.0 °Brix, 14th March = 11.3 °Brix and 27th March = 12.4 °Brix (n=30 fruit). The TSS level at harvest for long term CA storage should be greater than 12 °Brix (Chennell, et. al., 2002).
After 8.5 months the total soluble solids (°Brix) of Granny Smith apples treated with SmartFresh was not significantly different to untreated fruit (Table 5). However, after 11 months, SmartFresh treated fruit had significantly higher TSS levels compared to non-SmartFresh treated fruit. TSS levels were commercially acceptable after storage.

**Skin Colour**

The average skin colour (hue angle =h°) for Granny Smith apples at harvest were on the 28th February = 116.6 °, 14th March = 120 ° and 27th March = 119.9 °. The fruit was a green-yellow colour ideal for long term storage.

After 8.5 and 11 months storage SmartFresh treated fruit were greener than untreated fruit (Table 6). There was no significant effect of harvest date on the ground colour of SmartFresh treated fruit after 11 months storage. The fruit had excellent skin colour (Plate 1). The skin colour of all non-SmartFresh treated fruit after 11 months were unacceptable.

**Incidence of rots**

The incidence of storage rots in Granny Smith apples treated with SmartFresh compared to non-SmartFresh treated fruit when assessed after 8.5 months and 11 months at 0°C in CA storage were not significantly different. Except for fruit harvested on the 14th March, after 8.5 months storage which was significantly different (Table 7).

**Internal browning**

The incidence and severity of internal browning was recorded after 8.5 months storage for the 3rd harvest only.

The incidence of internal browning in Granny Smith apples was significantly less in fruit treated with SmartFresh compared with non-SmartFresh treated fruit after 8.5 months at 0°C storage (Table 8, see internal browning photographs page 6).

The severity of internal browning in Granny Smith apples was significantly less in fruit treated with SmartFresh compared with non-SmartFresh treated fruit after 8.5 months at 0°C storage (Table 9).

The incidence of internal browning in Granny Smith apples was significantly less in fruit treated with SmartFresh compared with non-SmartFresh treated fruit after 11 months at 0°C storage (Table 10). There was no significant effect of harvest date on the incidence of internal browning.

**Core flush**

Core flush was only recorded for fruit harvested on the 27th March, after 11 months storage. The incidence and severity of core flush was significantly reduced by SmartFresh after 11 months storage at 0°C (Table 11, see core flush rating photographs page 7).

Fruit not treated with SmartFresh had an unacceptable incidence and severity of core flush, being 74.4% and 2.9 rating respectively. The incidence of core flush in SmartFresh treated fruit was 24% but the severity rating was low at 1.4 and the fruit was saleable.
4. DISCUSSION AND CONCLUSIONS

The results of this work have shown that SmartFresh at 625 ppb can control superficial scald for up to 11 months which would enable the growers to supply scald free apples almost all year round. However, SmartFresh did not give a 100 percent control of superficial scald. In selected harvests approximately 1.8% of the fruit had superficial scald but the severity of the scald was very low and unlikely to affect the saleability of the fruit.

Superficial is generally higher in early picked fruit compared to later harvests. In this trial after 8.5 months storage the earliest picked fruit had the lowest incidence and severity of superficial scald. Superficial scald can be low if the fruit is harvested very early which was the case in this trial

SmartFresh did not effect the incidence of sunscald development in the 2001 (Wilkinson et al., 2001) and 2002 trials.

Core flush is a major internal disorder, appearing markedly after 6 months of storage (Hall and Scott, 1977, Zanella, 2003). It appears as brown tissue next to the carpels within the core but remains firm and dry. When the disorder is severe it may spread out into the flesh as a rather dry breakdown. The disorder develops rapidly after storage when the apples are transferred to warm conditions. Treating Granny Smith apples with SmartFresh has been reported to significantly reduce the incidence of core flush (Fan and Mattheis, 1999 and Zanella, 2003). The results from this trial have reconfirmed the previous findings. However, importantly, the severity of the core flush in the SmartFresh treated fruit was very low and unlikely to affect the saleability of the fruit compared to non-SmartFresh treated fruit which were unmarketable.

In this trial the fruit were examined for internal browning (IB) even though it was not part of the original proposal. This was prompted by two reasons 1. The internal browning problems linked to Pink Lady and 2. For CO2 sensitive apple varieties SmartFresh can increase the risk of internal browning. It is noted that Granny Smith is a CO2 sensitive variety. The symptoms of internal browning were mainly in the cortex and diffuse. However, core flush was recorded within the overall rating for IB. Internal browning was not a serious problem for Granny Smith apples picked on the 28th February (approximately 2.6% of the non-SmartFresh treated fruit had IB) and the 14th March (no IB observed) after 8.5 months storage. However, the incidence was much higher for fruit picked on the 27th March with 31.1 % of non-SmartFresh treated fruit and 7.8% of SmartFresh treated fruit with IB. However, the severity was very low and unlikely to affect fruit sales. After 11 months storage the incidence of IB for all harvest dates was much higher ranging from 78.9% to 94.4% for non-SmartFresh treated fruit and for SmartFresh treated fruit ranging from 24.4% to 28.5%. Fruit treated with SmartFresh were saleable whereas the non-SmartFresh treated fruit were not.

SmartFresh prevented serious internal browning and core flush in Granny Smith apples after long term CA storage.

An unusual internal breakdown disorder was observed in SmartFresh treated fruit. The breakdown appeared as scatter patches of soft moist orange-brown tissue within the fruit cortex (Plate 4). The breakdown was observed in two fruit (n = 180 fruit) treated with SmartFresh and was not observed in non-SmartFresh treated fruit.

Zanella, 2003 observed a CO2 like disorder on the skin of Granny Smith apples treated with SmartFresh. In this work some fruit treated with SmartFresh had patches of smoky looking skin (Plate 5). The 'smokiness' maybe the early stages of superficial scald or chlorophyll degradation or it may be a SmartFresh induced disorder similar to that which is caused by using too
high a DPA concentration which causes the fruit develop an overall dull appearance (Little and Holmes, 2000).

SmartFresh will keep Granny Smith apples firm and crunchy for 11 months and the fruit will have acceptable sugar levels. However, as ethylene regulates the production of volatile compounds that contribute to fruit aroma, SmartFresh delays the production of these compounds for several months. While the effect potentially alters the fruit aroma and flavour, Mattheis and Fan (2001) reported that the effects of SmartFresh on volatile production are similar to that induced by CA storage. Further research is needed to evaluate the effect of SmartFresh on aroma production and flavour and hence the consumer acceptance of the fruit after long-term storage.

5. RECOMMENDATIONS

Further work is needed to:
• Demonstrate the effectiveness of SmartFresh for scald control in commercial trials.
• Determine the effect of SmartFresh on the eating quality.

6. REFERENCES


Hall, E.G. and Scott, K. J. 1977. Storage and market diseases of fruit. Collected supplements I-XXIV reprinted from 'CSIRO Food Research Quarterly'.


7. TABLES

**Table 1.** Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the incidence of superficial scald in Granny Smith apples after 8.5 months and 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh Concentration</th>
<th>Superficial scald incidence (%)</th>
<th>Harvest</th>
<th>28th February</th>
<th>14th March</th>
<th>27th March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Storage</td>
<td>8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td>0 ppb¹</td>
<td></td>
<td></td>
<td>46.4</td>
<td>77.2</td>
<td>75.6</td>
</tr>
<tr>
<td>625 ppb</td>
<td></td>
<td></td>
<td>0.0</td>
<td>1.8</td>
<td>0.0</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td>Comparing across</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comparing down</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. ppb = concentration of parts per billion.
2. LSD = Least significant differences at the 5% significance level.

**Table 2.** Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the severity of superficial scald in Granny Smith apples after 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh Concentration</th>
<th>Severity rating³</th>
<th>Harvest</th>
<th>28th February</th>
<th>14th March</th>
<th>27th March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Storage</td>
<td>8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td>0 ppb¹</td>
<td></td>
<td></td>
<td>3.9</td>
<td>1.0</td>
<td>3.4</td>
</tr>
<tr>
<td>625 ppb</td>
<td></td>
<td></td>
<td>1.0</td>
<td>1.0</td>
<td>0.3</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td>Comparing across</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comparing down</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

³. Severity rating scale: 1 = none, 2 = trace, 3 = slight, 4 = moderate and 5 = severe (see rating photographs page 7).

**Table 3.** Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the incidence of sunburn scald in Granny Smith apples after 8.5 months and 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh Concentration</th>
<th>Sunburn scald incidence (%)</th>
<th>Harvest</th>
<th>28th February</th>
<th>14th March</th>
<th>27th March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Storage</td>
<td>8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td>0 ppb¹</td>
<td></td>
<td></td>
<td>4.5</td>
<td>4.4</td>
<td>5.6</td>
</tr>
<tr>
<td>625 ppb</td>
<td></td>
<td></td>
<td>8.3</td>
<td>7.4</td>
<td>0.0</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td>Comparing across</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comparing down</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the firmness in Granny Smith apples after 8.5 months and 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh Concentration</th>
<th>Harvest 28th February</th>
<th>14th March</th>
<th>27th March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Storage 8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td></td>
<td>8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td>0 ppb¹</td>
<td>7.9</td>
<td>7.4</td>
<td>7.7</td>
</tr>
<tr>
<td>625 ppb</td>
<td>8.3</td>
<td>8.6</td>
<td>8.1</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparing across</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparing down</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the total soluble solids content in Granny Smith apples after 8.5 months and 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh Concentration</th>
<th>Harvest 28th February</th>
<th>14th March</th>
<th>27th March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Storage 8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td></td>
<td>8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td>0 ppb¹</td>
<td>12.9</td>
<td>12.2</td>
<td>13.1</td>
</tr>
<tr>
<td>625 ppb</td>
<td>12.9</td>
<td>12.6</td>
<td>13.2</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparing across</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparing down</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the ground colour in Granny Smith apples after 8.5 months and 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh Concentration</th>
<th>Harvest 28th February</th>
<th>14th March</th>
<th>27th March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Storage 8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td></td>
<td>8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td>0 ppb¹</td>
<td>111.7</td>
<td>108.3</td>
<td>111.6</td>
</tr>
<tr>
<td>625 ppb</td>
<td>114.3</td>
<td>112.5</td>
<td>113.6</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparing across</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparing down</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹. ppb = concentration of parts per billion.
². LSD = Least significant differences at the 5% significance level.
Table 7. Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the incidence of rots in Granny Smith apples after 8.5 months and 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh Concentration</th>
<th>Rots incidence (%)</th>
<th>Harvest</th>
<th>28th February</th>
<th>14th March</th>
<th>27th March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Storage</td>
<td>8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td>0 ppb</td>
<td></td>
<td>1.1</td>
<td>6.7</td>
<td>1.1</td>
<td>11.1</td>
</tr>
<tr>
<td>625 ppb</td>
<td></td>
<td>3.3</td>
<td>3.9</td>
<td>8.9</td>
<td>10.0</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td>Comparing across</td>
<td>6.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comparing down</td>
<td>7.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8. Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the incidence and severity of internal browning in Granny Smith apples from the 3rd harvest, after 8.5 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh concentration (parts per billion)</th>
<th>Incidence of internal browning (%)</th>
<th>Severity of internal browning³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppb</td>
<td>31.1</td>
<td>1.4</td>
</tr>
<tr>
<td>625 ppb¹</td>
<td>7.8</td>
<td>1.1</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td>20.2</td>
<td>0.2</td>
</tr>
</tbody>
</table>

³ Severity rating scale: 1 = none, 2 = trace, 3 = slight, 4 = moderate and 5 = severe (see rating photographs page 6).

Table 9. Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the incidence of internal browning in Granny Smith apples after 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh Concentration</th>
<th>Internal browning incidence (%)</th>
<th>Harvest</th>
<th>28th February</th>
<th>14th March</th>
<th>27th March</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>8.5 months</td>
<td>11 months</td>
<td>8.5 months</td>
</tr>
<tr>
<td>0 ppb</td>
<td></td>
<td>93.3</td>
<td>94.4</td>
<td>78.9</td>
<td></td>
</tr>
<tr>
<td>625 ppb</td>
<td></td>
<td>24.4</td>
<td>28.5</td>
<td>24.4</td>
<td></td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td>Comparing across</td>
<td>19.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Comparing down</td>
<td>22.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ ppb = concentration of parts per billion  
² LSD = Least significant differences at the 5% significance level.
Table 10. Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the severity of internal browning in Granny Smith apples after 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh Concentration</th>
<th>Internal browning severity³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvest</td>
<td>28th February</td>
</tr>
<tr>
<td>0 ppb¹</td>
<td>3.2</td>
</tr>
<tr>
<td>625 ppb</td>
<td>1.4</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td></td>
</tr>
<tr>
<td>Comparing across</td>
<td></td>
</tr>
<tr>
<td>Comparing down</td>
<td></td>
</tr>
</tbody>
</table>

³ Severity rating scale: 1 = none, 2 = trace, 3 = slight, 4 = moderate and 5 = severe (see rating photographs page 7).

Table 11. Effect of SmartFresh (625 ppb for 24 hours at 20°C) on the incidence and severity of core flush in Granny Smith apples after 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1.0% CO₂) followed by 7 days at 20°C.

<table>
<thead>
<tr>
<th>SmartFresh concentration (parts per billion)</th>
<th>Incidence of core flush (%)</th>
<th>Severity of core flush³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ppb</td>
<td>74.4</td>
<td>2.9</td>
</tr>
<tr>
<td>625 ppb</td>
<td>24.4</td>
<td>1.4</td>
</tr>
<tr>
<td>LSD² (P=0.05)</td>
<td>24.1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

³ Severity rating scale: 1 = none, 2 = trace, 3 = slight, 4 = moderate and 5 = severe (see rating photographs page 7).

¹ ppb = concentration of parts per billion
² LSD = Least significant differences at the 5% significance level.
8. PLATES

A. Granny Smith apples harvested on the 28th February 11 months CA storage plus 7 days at 20°C.

B. Granny Smith apples harvested on the 14th March, 11 months plus 7 days at 20°C.

C. Granny Smith apples harvested on the 27th March, 2002, after 11 months plus 7 days at 20°C.

Plate 1. Granny Smith apples treated with SmartFresh (625 ppb for 24 hours at 20°C) were greener and had no superficial scald after 11 months at 0°C in controlled atmosphere storage (2.5% O₂ plus 1% CO₂) (right) compared non SmartFresh treated fruit with severe scald and skin yellowing (left).
Plate 2. Granny Smith apple treated with SmartFresh after 11 months storage showing typical sun scald.
A. Starch iodine test on Granny Smith apples harvested on the 28th February, 2002.

B. Starch iodine test on Granny Smith apples harvested on the 14th March, 2002.


Plate 3. Show the iodine starch patterns for Granny Smith apples harvested on 28th February, 14th March and 27th March.
Plate 4. Granny Smith apple with an undefined disorder observed in SmartFresh treated fruit.
Plate 5. Granny Smith apples with an undefined skin disorder, 'smokiness' which maybe the early stages of superficial scald, chlorophyll degradation or it may be a SmartFresh induced disorder. If DPA is used at too high a concentration the fruit develop an overall dull appearance described as 'smokiness' in Little and Holmes (2000) Chapter 7 page 249.
7.4 Effect of 1-MCP on Red Delicious apples - 2002 Season

7.4.1 Materials and Methods

Experimental Design

This season’s trials were designed to test the effect of harvest maturity on the performance of 1-MCP. Red Delicious apples were harvested from Batlow at three different maturities, at the commercial harvest and one week before and after this date.

The ‘treated’ fruit were fumigated for 24 hours with 625 ppb of 1-MCP in individual (150L) airtight tubs at 20°C. Each tub also contained an open tray of 20% potassium hydroxide (50ml) to absorb carbon dioxide.

A stock of 20 000 000 ppb 1-MCP was prepared and a gas sample was withdrawn with a syringe and injected into the treatment chambers to give a concentration of 625 ppb.

After treatment the fruit was transferred to CA storage, 2.5% O₂: 1%CO₂ (again in individual tubs) at 0°C. Fruit was assessed for scald, firmness, TSS, internal browning and rots after 6 and 9 months storage, followed by 7 days ripening at 20°C.

This is a three-phase design with a field phase, SmartFresh (1-MCP) treatment phase followed by a storage phase. There were 6 replicates of each treatment combination. In the field, there were 6 blocks (replicates) of trees from which at each harvest date 4 bags of 30 fruit were picked. In the SmartFresh treatment phase, at each harvest within each of the 6 blocks, the 4 bags from the field were allocated to 2 tubs containing 2 bags. The 2 SmartFresh concentrations were randomised to the 2 tubs within each block. In the storage phase, the bags of fruit in the 12 tubs were moved into the 6 blocks of 2 storage tubs in the storage room. After all 3 harvests were treated; each storage tub contained 6 bags of fruit for the 2 storage times by 3 harvest dates randomly positioned within each tub.

Statistical Analysis

Results were statistically analysed using ANOVA, GenStat for Windows 5th edition (Lawes Agricultural Trust, IACR-Rothamsted) and significance determined using LSD’s at the 5% level. The LSD bars presented in the figures are for the comparison of 1-MCP treated and untreated fruit. LSD’s for comparing storage duration and harvest are not presented.

7.4.2 Results

The apples treated with 1-MCP developed no scald after 6 or 9 months storage. The untreated fruit developed some scald (2-6%) on the commercial and early harvested fruit after 6 months storage, while after 9 months all harvests had significant amounts of scald. (Table 7.1).

The treated fruit also showed significant improvement in firmness due to the 1-MCP treatment, and the commercial harvest showed increased TSS when treated. (Fig 7.1).

There was no significant difference in the occurrence of rots or internal browning due to the 1-MCP treatment.

Table 7.1 % Scald occurrence on 1-MCP treated and untreated Red Delicious apples after 6 and 9 months storage.

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>STORAGE LENGTH</th>
<th>HARVEST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Harvest 1</td>
<td>Harvest 2</td>
</tr>
<tr>
<td>1-MCP</td>
<td>6 months</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>9 months</td>
<td>0</td>
</tr>
<tr>
<td>Untreated</td>
<td>6 months</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>9 months</td>
<td>25</td>
</tr>
</tbody>
</table>
Figure 7.1 The effect of 1-MCP fumigation on the firmness and TSS of Red Delicious apples stored for 6 or 9 months in CA. Error bars are LSD ($P=0.05$) for the comparison of 1-MCP treated and untreated.

### 7.5 Discussion

The 1-MCP treatment provided excellent scald control on Red Delicious for up to 9 months storage and Granny Smith for 11 months, as well as delaying softening and yellowing which will lead to increased shelf life. No detrimental effects on quality were observed. 1-MCP did not affect the occurrence of rots or internal browning on Red Delicious, while on Granny Smith in 2002 the incidence and severity of internal browning decreased with 1-MCP treatment.

It is likely that 1-MCP will be a useful alternative to DPA for scald control on a number of apple varieties. 1-MCP is attractive because it is applied at very low concentrations (less than 1ppm), it is easy to apply, as a fumigant, easy to dispose of, and it avoids dipping.

Consumer acceptance of 1-MCP treated fruit has not been tested, as it is not yet registered for use in Australia. When possible, further investigation of eating quality/flavour development is necessary. Lurie et al (2002) report that Anna apples treated with 1µl /L 1-MCP developed less ripe aromas than control fruit or fruit treated with 0.1µl /L 1-MCP, although the consumer preference was for the fruit treated with the higher concentration.

The concentrations and fumigation times needed to successfully treat a range of horticultural produce varies greatly (Sisler and Serek 1997), and there is considerable variation in the response of individual apple cultivars (Watkins et al. 2000). Determining the optimal treatment range is important to ensure that the treatment is effective and that normal ripening occurs once the fruit are marketed.
8. ALCOHOL VAPOUR

8.1 Introduction

Alcohol vapour has been reported to be an effective control against superficial scald. It may act by reducing the production of α-farnesene and preventing its breakdown to conjugated trienes (Ghahramani and Scott 1998, Ghahramani et al. 1999), the substances that are thought to cause scald.

Scott et al. (1995) showed that 0.5 to 1 g of ethanol per fruit completely controlled scald on Granny Smith apples. The ethanol was vaporised inside sealed polyethylene bags containing the apples. However at effective concentrations, in some circumstances, it caused purpling of the skin in red varieties (Ghahramani et al. 2000).

Ghahramani et al. (2000) also demonstrated that other alcohols, propan-1-ol and butan-1-ol, are also effective scald inhibitors.

During 2000-2002 large-scale trials for this project were conducted in South Australia (SARDI). The efficacy of alcohol for scald control was tested in a coolstore situation (12 bin CA rooms). Some smaller trials on combinations of alcohols and delayed application were conducted at IHD.

Initially ethanol vapour was used. According to the food standards code (www.foodstandards.gov.au/foodstandardscode) ethanol is accepted as a processing aid, carrier, solvent and diluent and may be used in the manufacture of food provided the final food contains no more than the maximum permitted level. To obtain sufficient quantities for use as a postharvest treatment, without incurring excise tax, proper authorisation would need to be obtained and it may need to have a denaturant added to make it undrinkable.

In subsequent years the use of propanol was investigated. Iso-propanol is accepted as a solvent in food flavouring and is generally permitted as a processing aid, carrier, solvent and diluent. Propanol is also effective at lower concentrations than ethanol and is not known to cause discolouration of red varieties.

Commercial application will require regulatory approval even though alcohols are regularly consumed as food.
8.2 Ethanol — Coolstore trials

8.2.1 Materials and Methods

Experimental Design

Fruit of the apple varieties Red Delicious, Granny Smith, Pink Lady and Fuji and the pear variety Packham’s Triumph were obtained from commercial orchards in the Adelaide Hills during the 2000 season. Fruit of each variety was picked at the forecast harvest date for long term storage (calculated from green tip date and temperature data) and at 2 weeks before this date. At harvest, fruit maturity factors (starch index, sugar and firmness) were measured. Fruit was cooled to 0°C and stored for up to 3 weeks prior to application of treatments for the control of superficial scald. Half the fruit was treated by fumigation with 1.2 L ethanol per bin (equivalent to 0.07 mol/kg) plus the denaturant Bitrex @ 13 ppm. Ethanol was placed in a gravel bed in front of the forced draft coils and the cool room left sealed for 2 weeks. Carbon dioxide was controlled by the use of lime. After 2 weeks, controlled atmosphere storage was established (2.0% O₂: <0.5% CO₂). The other half of the fruit was left untreated and placed in a separate controlled atmosphere storage room. Both rooms contained the equivalent of 12 bins of fruit. Samples of 50 fruit were removed from storage and the incidence of superficial scald assessed after three storage times for each variety, with the time of storage ranging from 5-8 months. Fruit were examined after holding for 7 days at 20°C.

The ethanol treatment rooms were un-replicated so no statistical analysis of the data was done.

In the 2001 season fruit of the pear variety Packham’s Triumph were obtained from a commercial orchard in the Adelaide Hills. Fruit was picked at the forecast harvest date for long term storage and two weeks before this date. Packham’s Triumph pears were fumigated for 3 weeks at 0°C by sealing the fruit in plastic bags with ethanol at a rate of 3 g/kg of fruit (equivalent to 0.07mol/kg). After fumigation the fruit was placed in CA storage (2.0% O₂: <0.5% CO₂). Fruit samples were removed from storage and the incidence of superficial scald assessed after each of three storage times, with the time in storage ranging from 5 to 8 months.

8.2.2 Results

Red Delicious

Red Delicious apples were harvested on 24/2/2000 and 9/3/2000. At the first harvest the starch score was 1.2 (using the 1-5 scale) and at the second harvest starch score was 1.8. Firmness values were 9.1 kg at both harvests. TSS levels were 9.2 and 10.0°Brix at harvests 1 and 2 respectively.

Incidence of superficial scald was high at the first removal from storage (6 months). Fumigation with ethanol (1.2 L/bin) did not control scald in this instance (data not shown).

Fuji

Fuji apples were harvested on 17/3/2000 and 30/3/2000. At the first harvest the starch score was 2.6 and at the second harvest starch score was 3.0. Firmness values were 9.3 and 8.2 kg for harvests 1 and 2 respectively. TSS levels were 12.8 and 13.3°Brix at harvests 1 and 2 respectively.

Incidence of superficial scald on untreated Fuji apples out of storage was high. After 5 months storage 90% of apples from harvest 1 showed scald and 34% from harvest 2 showed scald (Fig 8.1). Fumigation with ethanol (1.2 L/bin) slightly reduced scald on fruit from harvest 1, but levels were still above 70% after 5 months of storage. Scald was controlled on Fuji apples from harvest 2 for 5 months, but levels of scald were commercially unacceptable (10%) after 6 months storage.
Figure 8.1 Incidence of scald on early and commercial harvested Fuji apples in CA storage with and without ethanol fumigation.

Granny Smith

Granny Smith apples were harvested on 10/4/2000 and 26/4/2000. At the first harvest the starch score was 3.5 and at the second harvest starch score was 3.8. Firmness values were 8.6 and 7.6 kg for harvests 1 and 2 respectively. TSS levels were 11.7°Brix at both harvests.

Incidence of superficial scald on untreated Granny Smith apples out of storage was high. After 5 months storage 84% of Granny Smith apples from harvest 1 showed scald and 44% of Granny Smith apples from harvest 2 showed scald (Fig 8.2). Fumigation with ethanol (1.2 L/bin) did not provide any control of scald on fruit from harvest 1, with levels of scald being as high or higher than for untreated apples. Fumigation with ethanol reduced the incidence of scald out of storage on apples from harvest 2, but levels of scald were commercially unacceptable (28%) after 5 months storage.

Figure 8.2 Incidence of scald on early and commercial harvested Granny Smith apples in CA storage with and without ethanol fumigation.

Pink Lady

Pink Lady apples were harvested on 10/4/2000 and 26/4/2000. At the first harvest the starch score was 2.6 and at the second harvest starch score was 4.0. Firmness values were 10.4 and 9.2 kg for harvests 1 and 2 respectively. TSS levels were 12.4 and 13.2°Brix at harvests 1 and 2 respectively.

Incidence of superficial scald on untreated Pink Lady apples from harvest 1 was high. After 5 months storage 100% of Pink Lady apples from harvest 1 showed scald (Fig 8.3). Delay in
harvest of 2 weeks resulted in less scald out of storage with only 6% of Pink Lady apples from harvest 2 showing scald after 5 months storage. Fumigation with ethanol (1.2 L/bin) slightly reduced scald on fruit from harvest 1, but levels were still above 70% after 5 months of storage. Fumigation with ethanol controlled scald out of storage for at least 7 months on Pink Lady apples from harvest 2.

Packham’s Triumph pears

In year 1 Packham’s Triumph pears were harvested on 10/2/2000 and 24/2/2000. Firmness values were 6.6 and 6.0 kg for harvests 1 and 2 respectively.

Untreated Packham’s Triumph pears did not show superficial scald after 5 months of storage (Fig 8.4). After 7 months storage 42% of pears from harvest 1 showed scald. Delaying harvest by 2 weeks resulted in less scald out of storage with only 14% of Packham’s Triumph pears from harvest 2 showing scald after 7 months storage. Fumigation with ethanol (1.2 L/bin) controlled scald out of storage for 7 months on Packham’s Triumph pears from both harvest 1 and 2. After 8 months very slight scald appeared on 2 to 6 % of pears fumigated with ethanol.

Figure 8.3 Incidence of scald on early and commercial harvested Pink Lady apples in CA storage with and without ethanol fumigation.

Figure 8.4 Incidence of scald on early and commercial harvested Packham’s Triumph pears harvested in 2000 and storage in CA, with and without ethanol fumigation.
In year 2 Packham’s Triumph pears were harvested on 20/2/2001 and 5/3/2001. Firmness values were 6.0 and 7.1 kg for harvests 1 and 2 respectively.

Incidence of superficial scald on pears was higher in the second season than the first. After 5 months of storage 10% of untreated pears from harvest 1 showed scald and 12% of pears from harvest 2 showed scald (Fig 8.5). Fumigation with ethanol (3 g/kg) controlled scald out of storage for 5 months on Packham’s Triumph pears from harvest 1 and 7 months from harvest 2.

![Graph showing the incidence of scald on Packham's Triumph pears harvested in 2001 and stored in CA, with and without ethanol fumigation.](image)

**Figure 8.5** Incidence of scald on early and commercial harvested Packham’s Triumph pears harvested in 2001 and stored in CA, with and without ethanol fumigation.

In both seasons pears fumigated with ethanol coloured to a deeper yellow when ripened after storage, and developed a lustre not seen in untreated fruit. Towards the end of the storage, texture of the ethanol fumigated pears when ripened was firmer, less juicy and more grainy than that of untreated fruit. The changes in pear quality observed were of sufficient magnitude to adversely affect marketing of treated fruit.

No tainting or alcoholic flavours were detected in Packham’s Triumph pears treated with ethanol at rates up to 3 g/kg.
8.3 Propan-1-ol — Coolstore trials

8.3.1 Materials and Methods

Experimental Design

Fruit of the apple varieties Granny Smith and Pink Lady were obtained from commercial orchards in the Adelaide Hills. Fruit of each variety was picked at the forecast harvest date for long term storage and two weeks before this date. Granny Smith apples (5 bins) and Pink Lady apples (¼ bin) from each harvest were cooled to 0°C within 48 hours of harvest and placed in CA storage (2.0% O₂: <0.5% CO₂). Fruit from both varieties and harvests were consolidated and treated at the one time by fumigation with 450 mL of propan-1-ol per bin (equivalent to 0.015mol/kg) in a sealed controlled atmosphere room for 4 weeks. During the 4 week treatment time the room was not purged and carbon dioxide was controlled by lime placed in the room. Fumigation was carried out by piping the propan-1-ol into a gravel bed situated in front of the cooling fans, thus maintaining CA storage. Additionally, Granny Smith apples (1 bin) and Pink Lady apples (¼ bin) from the same harvests as above were cooled in a separate room and CA established. Fruit samples were removed from storage and the incidence of superficial scald assessed four times for each variety, with the time in storage ranging from 3 to 9 months.

The treatment rooms were un-replicated so no statistical analysis of the data was done. Scald was measured on 100 Granny Smith apples and 50 Pink Lady at each removal date.

Residue Procedures

Fruit was sampled four weeks after fumigation from the centre of all bins for propan-1-ol residue analysis and tasting for alcoholic flavours. Fruit were sampled from 21 positions throughout a bin of Granny Smith apples from each of the 2 harvests. Samples were taken from the centre of bins of Pink Lady apples for each harvest.

Apples were sent via refrigerated transport to IHD for analysis. Upon arrival the apples were frozen until they could be prepared.

Frozen apples were thawed slowly at 2°C and juiced. A combined sample of the juice from 5 apples was then centrifuged and filtered. Samples were stored at −70°C for later analysis.

1µl of juice was injected into the gas chromatograph (Shimadzu GC-14B, with FID detector). The column used was packed stainless steel 3m X 1/8”, 5% FFAP on Chromsorb G-AW-DMCS, 60/80 mesh (Alltech). The temperature program used was: start temperature 50°C held for 1 minute, increase from 50°C to 150°C at a rate of 10°C per minute, held at 150° for 1 minute.

8.3.2 Results

Granny Smith

Granny Smith apples were harvested on 10/4/2001 and 23/4/2001. At the first harvest the starch score was 3.4 and at the second harvest starch score was 3.9. Firmness values were 8.7 and 8.2 kg for harvests 1 and 2 respectively. TSS levels were 13.7°Brix and 13.8°Brix at harvests 1 and 2 respectively.

Superficial scald did not occur in the first 3 months of storage. After 5 months storage 33% of Granny Smith apples from harvest 1 showed scald and 30% of Granny Smith apples from harvest 2 showed scald with over 95% of untreated apples showing scald after 7 months storage (Fig 8.6). Fumigation with propan-1-ol (450 mL/bin) controlled scald on fruit from harvest 1 for 7 months and for at least 9 months on fruit from harvest 2.

Fruit treated with propan-1-ol developed areas of brown discoloration on the margins of areas of sunburn. This discoloration that resembled sunburn scald was evident from the first removal from storage at 3 months.
Figure 8.6 Incidence of scald on early and commercial harvested Granny Smith apples stored in CA with and without propanol fumigation.

Levels of propan-1-ol in the extracted juice of fruit measured at the end of fumigation averaged 0.27 g/L for harvest 1 and 0.25 g/L for harvest 2. Levels of individual samples varied from 0.09 to 0.61 g/L. However there were no consistent differences with position of sampling in the bins.

Fruit was tainted to the point of inedibility when tasted 4 weeks after fumigation with propan-1-ol. Tainting of the fruit was still noticeable when tasted immediately out of storage after 3 months. Tainting decreased with time in storage and was not discernible in Granny Smith apples after 5 months for fruit picked at harvest 1 and after 7 months for fruit picked at harvest 2. When apples were taken out of storage and left at 20°C for 7 days, tainting of the fruit tended to decrease.

Pink Lady

Pink Lady apples were harvested on 10/4/2001 and 23/4/2001. At the first harvest the starch score was 3.0 and at the second harvest starch score was 4.4. Firmness values were 9.7 and 8.2 kg for harvests 1 and 2 respectively. TSS levels were 15.6 and 13.7°Brix at harvests 1 and 2 respectively.

Superficial scald did not occur in the first 5 months of storage. After 7 months storage 48% of Pink Lady apples from harvest 1 showed scald (Fig 8.7). Delay in harvest of 2 weeks resulted in less scald out of storage with only 16% of Pink Lady apples from harvest 2 showing scald after 7 months storage. Fumigation with propan-1-ol (450 mL/bin) controlled scald out of storage for at least 9 months on Pink Lady apples.

Figure 8.7 Incidence of scald on early and commercial harvested Pink Lady apples stored in CA with and without propanol fumigation.
Levels of propan-1-ol in the extracted juice of fruit measured at the end of fumigation were 0.5 g/L for harvest 1 and 0.83 g/L for harvest 2. Fruit was tainted to the point of inedibility when tasted 4 weeks after fumigation with propan-1-ol. Tainting of the fruit was also noticeable when tasted immediately out of storage up until the last removal at 9 months. Fruit removed at 7 months had unacceptable levels of tainting. When apples were taken out of storage and left at 20°C for 7 days, tainting of the fruit tended to decrease.
8.4 Propan-2-ol (Iso-propanol) — Coolstore trials

8.4.1 Materials and Methods

Fruit of the apple varieties Granny Smith and Pink Lady were obtained from commercial orchards located in the Adelaide Hills. Fruit of each variety were picked at the forecast harvest date for long term storage and at two weeks before this date. Equal quantities of Granny Smith apples (5 bins) and Pink Lady apples (¼ bin) from each harvest were consolidated and treated at the one time by fumigation with 230 mL of propan-2-ol per bin (equivalent to 0.0075mol/kg) in a sealed room for two weeks. Controlled atmosphere (CA) was established in the room prior to fumigation. Fumigation was carried out by piping the propan-2-ol into a gravel bed situated in front of the cooling fans. During the 2 week treatment time the room was not purged and carbon dioxide was controlled by lime placed in the room. Additionally, Granny Smith apples (1 bin) and Pink Lady apples (¼ bin) from the same harvests as above were cooled in a separate room and CA established.

Fruit was sampled four weeks after fumigation from the centre of all bins for propan-2-ol residue analysis and tasting for alcoholic flavours. Fruit were sampled from each bin of Granny Smith apples throughout the room from each of the 2 harvests. Two samples were taken from the centre of bins of Pink Lady apples for each harvest. Fruit was sent under refrigeration to IHD where they were frozen for future analysis. Analysis for propanol residues was conducted as described in section 8.3.1.

The ethanol treatment rooms were un-replicated so no statistical analysis of the data was done. Scald was measured on 100 Granny Smith apples and 50 Pink Lady at each assessment date.

8.4.2 Results

Granny Smith

Granny Smith apples were harvested on 9/4/2002 and 23/4/2002. At the first harvest the starch score was 2.2 and at the second harvest starch score was 3.3. Firmness values were 9.7 and 8.9 kg for harvests 1 and 2 respectively. TSS levels were 10.8°Brix and 12.1°Brix at harvests 1 and 2 respectively.

Incidence of superficial scald on untreated Granny Smith apples out of storage was high. After 4 months storage 97% of Granny Smith apples from harvest 1 showed scald and 73% of Granny Smith apples from harvest 2 showed scald (Fig 8.8). Fumigation with propan-2-ol (230 mL/bin) did not provide control of scald, with the levels of scald out of storage being as high or higher for treated as untreated apples.

![Graph showing scald incidence for Granny Smith apples harvested on 9/4/2002 and 23/4/2002 with and without propanol fumigation.]

![Graph showing scald incidence for Granny Smith apples harvested on 23/4/2002 with and without propanol fumigation.]

Figure 8.8 Incidence of scald on early and commercial harvested Granny Smith apples stored in CA with and without propanol fumigation.
Levels of propan-2-ol in the extracted juice of fruit measured at the end of fumigation averaged 0.15 g/L for harvest 1 and 0.14 g/L for harvest 2. Levels measured for individual bins ranged from 0.08 to 0.25 g/L. When fruit was tasted 4 weeks after fumigation, the treated fruit had a slightly different flavour to untreated fruit. After 4 months in storage there was still a slight difference in the flavour of the fruit, but the flavour was acceptable. This difference in flavour was no longer discernible after 6 months in storage or after fruit was held at 20°C for 7 days.

**Pink Lady**

Pink Lady apples were harvested on 9/4/2002 and 23/4/2002. At the first harvest the starch score was 1.1 and at the second harvest starch score was 3.2. Firmness values were 10.8 and 9.8 kg for harvests 1 and 2 respectively. TSS levels were 12.4 and 13.2°Brix at harvests 1 and 2 respectively.

Scald did not occur on untreated Pink Lady apples until after 8 months of storage. After 8 months storage 32% of Pink Lady apples from harvest 1 showed scald (Fig 8.9). Delay in harvest of 2 weeks resulted in less scald out of storage with only 7% of Pink Lady apples from harvest 2 showing scald after 8 months storage. Fumigation with propan-2-ol (230 mL/bin) did not control scald out of storage, with incidence of scald being similar to untreated fruit.

![Pink Lady graphs](image)

**Figure 8.9** Incidence of scald on early and commercial harvested Pink Lady apples stored in CA with and without propanol fumigation.

Levels of propan-2-ol in the extracted juice of fruit measured at the end of fumigation were 0.14 g/L for harvest 1 and 0.10 g/L for harvest 2. When fruit was tasted 4 weeks after fumigation, the treated fruit had a slightly different flavour to untreated fruit. After 4 months in storage there was still a slight difference in the flavour of the fruit, but the flavour was acceptable. This difference in flavour was not discernible after 6 months in storage or after fruit was held at 20°C for 7 days.
8.5 Combinations of Ethanol and Propan-1-ol

While ethanol has been shown to provide effective scald control there is some concern that it may cause abnormal skin colouration in some red varieties. There is also evidence that propanol may be more effective at controlling scald at lower concentrations and volumes. The combination of ethanol and propanol was investigated in order to determine the effect of combining these alcohols on scald control and colour development during storage.

8.5.1 Materials and Methods

The effective rates of ethanol and propanol were found by Ghahramani et al. (2000) to be 0.12 mol/kg of ethanol and 0.03 mol/kg of propanol, when applied in an enclosed space containing the apples. Four levels of treatment were applied, a control with no alcohol, 100% ethanol at 0.12 mol/kg, and two combinations of ethanol and propan-2-ol. The mixtures of ethanol and propanol used were 0.108 mol/kg ethanol and 0.003 mol/kg propanol (90 and 10% of the active concentrations) and 0.09 mol/kg ethanol and 0.0075 mol/kg propanol (75 and 25% of the active concentrations).

Fuji apples of commercial maturity were harvested in the Yarra Valley. Five replicates of 80 fruit were harvested and 20 fruit exposed to each of the 4 treatments. The treatment was carried out in cardboard trays holding 20 apples. The alcohol was measured into small cups filled with sand and placed among the apples. The trays were enclosed in 20 µ high-density polyethylene bags and stored at 0°C. The sealed plastic bags were punctured after 3 weeks to allow exchange of air. Apples were assessed after 7 months storage in air at 0°C and 7 days ripening at 20°C for scald and firmness. Colour was assessed on both the red and green sides of the fruit after 1, 2, 5 and 7 days ripening.

Results were analysed using ANOVA, GenStat for Windows 5th edition (Lawes Agricultural Trust, IACR-Rothamsted) and significance determined using LSD’s at the 5% significance level.

8.5.2 Results

Although all ethanol and propanol combinations provided some scald reduction only the 90:10 ethanol:propanol mixture resulted in significantly less scald than the control fruit. There was no significant difference between the alcohol treatments (Fig 8.10).

![Figure 8.10](image)

**Figure 8.10** Average scald occurrence on Fuji apples fumigated with combinations of ethanol and propanol and stored in air. Error bar is LSD (P=0.5).
There was concern that fumigation with 100% ethanol may cause “purpling” in some red apples. However in this trial no abnormal colouration was observed. There were slight differences in the red colour depending upon which alcohol was used in the fumigation, but none of the colour levels differed significantly from the control.

There was a significant difference in the red colour between 100% ethanol and 90:10 ethanol: propanol. The hue angle measurements indicate that in this case the fruit treated with 100% ethanol are slightly less red than those treated with the ethanol/propanol mixture, where 0° is red and 90° is yellow. There was no significant difference in colour (hue angle), where 90° is yellow and 180° is green, on the yellow/green side of the fruit (Fig 8.11).

**Figure 8.11** The development of red and yellow colouration the 7 day ripening period for Fuji apples treated with alcohol fumigation. Error bar is LSD (P=0.5) for comparison of alcohol treatments.
8.6 Delayed Application of Propan-2-ol

A small trial was set up to investigate the effect of delayed application of alcohol on scald control. A delay in application would take into account the amount of time taken to fill a commercial coolroom before sealing and applying the treatment.

8.6.1 Materials and Methods

Granny Smith apples harvested in the Yarra Valley during 2001 were treated with propan-2-ol at either 0, 1, 2 or 4 weeks after harvest, at a rate of 0.0075 mol/kg. Five replicates of 20 apples were used for each treatment time. Apples were arranged in plastic trays in single layer cardboard boxes. The alcohol was measured into small plastic cups with cotton wool as an absorbent, and was placed in the centre of the box of apples. The boxes were then enclosed in plastic bags and stored in air at 0°C. The plastic bags were opened after 16 weeks and the fruit continued to be stored in air at 0°C.

Fruit was assessed after 7.5 months for scald occurrence and severity, firmness, colour and internal browning. Scald severity ratings, based on the percentage of surface area affected, were: 0 = 0%; 1 = 0-20%; 2 = 20-50%; 3 = 50-80% and 4 = 80-100%.

A follow up trial in the 2002 season was conducted in South Australia on Granny Smith apples harvested in the Adelaide Hills. Granny Smith apples harvested two weeks prior to the forecast harvest date were used to investigate the efficacy of delayed treatment with propan-2-ol for the control of superficial scald. In a non-replicated trial, 5 kg lots of fruit were sealed for 3 weeks in barrels with propan-2-ol at a rate of 1 g/kg of fruit (equivalent to 0.017 mol/kg) at times of 0, 1, 2, 3, 4, 6 and 12 weeks after harvest. Fruit was then air stored for 5 months at 0°C. Fruit was removed from storage and percentage of fruit showing superficial scald determined.

8.6.2 Results

Yarra Valley 2001

The incidence of superficial scald in this trial was 100% for all treatments; therefore the apples were assessed for the severity of scald.

Apples treated with propanol within a day of harvest (Day 0) showed significantly less severe scald than the control fruit or fruit with delayed treatment. (Fig 8.12).

There was no significant difference in firmness due to the propanol treatment. Fruit treated after 1 week and 2 weeks were significantly greener than control fruit (data not shown).

![Figure 8.12](image_url) The severity of scald on Granny Smith apples treated with propanol 0, 1, 2 or 4 weeks after harvest. Error bar is LSD (P=0.5).
Adelaide Hills 2002

A follow up trial in the 2002 season on Granny Smith apples harvested in the Adelaide Hills supported that delay in treatment reduces the efficacy of propan-2-ol for scald control. High levels of scald (66%) were found on untreated fruit after 5 months in air storage. When propan-2-ol was applied on the day of harvest the incidence of scald was reduced to 9%. The percentage of fruit that showed scald tended to increase with increased time between harvest and treatment (Fig 8.13). Where alcohol is used for scald control it should be applied as soon as possible after harvest.

Figure 8.13 The % of scalded Granny Smith apples in air storage, when propan-2-ol treatment is delayed by 0-12 weeks.
8.7 Discussion

Ethanol fumigation provided good control of superficial scald on Pink Lady apples and Packham’s Triumph pears when harvested at commercial maturity. Propan-1-ol provided control on Granny Smith and Pink Lady apples at commercial and early harvests. However flavour tainting was apparent in Pink Lady and Packham’s to an extent that would be detrimental to marketing. There was less, but still apparent, tainting in Granny Smith treated with propanol.

The rate of ethanol applied to apples and pears in year 1 of the project was at the lower end of the concentration range sufficient to control superficial scald. In this season the incidence of superficial scald on untreated fruit was high. Fumigation with ethanol did not provide adequate control of superficial scald on Red Delicious or Granny Smith apples, but was effective in controlling scald on Pink Lady apples when harvested at the forecast date for optimum long term storage. Control of scald was not adequate when Pink Lady apples were harvested 2 weeks before this date. Fumigation with ethanol provided control of superficial scald on Packham’s Triumph pears harvested at optimum maturity and 2 weeks prior to this date in 2000, but only when fruit was harvested at optimum maturity in 2001.

Failure to provide good scald control in other cultivars may have been partly due to the delay in application of ethanol for up to 3 weeks after harvest. It was shown that propan-2-ol is more effective when applied immediately after harvest.

Varying degrees of flavour tainting were detected in apple cultivars treated with ethanol, with the exception of Granny Smith. For this reason, increasing the dosage of ethanol fumigation was not considered to be an option to achieve satisfactory levels of control of superficial scald. Propanol provided control of superficial scald at lower application rates than ethanol, ie at 0.03 mol/kg of propanol compared with 0.12 mol/kg of ethanol. A second advantage of using propanol was that it would avoid the need to add a denaturant. For these reasons propan-1-ol and propan-2-ol rather than ethanol were trialed in subsequent years of the project.

Control of superficial scald obtained in the 2001 season by fumigation with 450 mL per bin of propan-1-ol was better than that achieved with 1.2 L per bin of ethanol in the 2000 season. This result may have been assisted by the establishment of CA prior to fumigation this season compared with after fumigation last season.

Propan-1-ol applied at a rate 450mL per bin provided control of superficial scald on Granny Smith and Pink Lady apples for at least 9 months of storage. However, at this rate of application the Pink Lady apples were tainted with an alcoholic flavour that made them unacceptable. Tainting of Granny Smith was less obvious, but was still detectable when fruit was tasted out of storage for the first 5 to 7 months depending on maturity.

Reducing the rate to 230 mL in the 2002 season overcame problems of fruit tainting, but scald was not controlled. It is possible that a rate of application between 230 and 450 mL could provide control without fruit tainting. Propan-2-ol (isopropyl alcohol) is permitted in foods with a concentration up to 1 g/kg. Average levels achieved in the fruit immediately after fumigation were well below this limit.

Trials investigating combinations of ethanol and propanol showed that the 90:10 ethanol:propanol mixture resulted in a significant reduction in scald, but the others did not. Propanol may be more effective than ethanol at controlling scald when used alone, however this did not extend to the 75:25 ethanol:propanol treatment. It may be that larger scale trials are needed to investigate its effectiveness. The bags used to hold the fruit for fumigation in this trial were semi-permeable to alcohol, so perhaps the fruit were not exposed to the correct concentration of alcohol vapour, leading to less than expected scald control.

Changes in colour of the alcohol treated fruit were not easily detectable to the eye and so are not likely to be of importance for marketability.
9. CANOLA OIL

9.1 Introduction

For several decades some degree of scald control was obtained commercially by wrapping fruit individually in tissue paper containing 15% mineral oil (Scott et al. 1995) or by distributing oil impregnated strips of paper throughout the apple cartons or bins (Ingle and D’Souza 1989). However, scald control under these conditions was not perfect and more effective means such as DPA were adopted.

Concerns about the use of DPA and the increasing desire for clean chemical-free produce have led to renewed investigation of the use of oils for scald control. Recently Scott et al. (1995) found that several vegetable oils, applied to the fruit by hand, considerably reduced the amount of scald developing on Granny Smith apples. However this application process would be time consuming and not practical commercially.

Other works (Ju et al. 2000) have shown that plant oil emulsions applied as a dip are effective in reducing the occurrence of scald. Ju et al. (2000) also found that several plant oils delayed ethylene production and helped in maintaining the firmness and greenness of Chinese pears.

The precise mode of action of the oils is not known. It is possible that they act as a physical barrier causing the modification of the fruits internal atmosphere. They may also act by to removing volatile substances from the fruit. Oiled wraps were found to absorb α-farnesene, a possible cause of scald, thus removing it and its oxidation products from the fruit (Huelin and Coggiola 1968).

Canola oil is widely available in Australia. It is a totally natural product, which would be acceptable for use on organically grown fruit and can be applied using existing dipping/drenching setups.
9.2 Combination Oil and CA - 2000 Season

9.2.1 Materials and Methods

Experimental Design

Trials were carried out on Red Delicious apples and Packham’s Triumph pears harvested in the Yarra Valley and Granny Smith apples harvested in the Goulburn Valley. There were 5 replicates of each treatment combination for each cultivar. Fruit was harvested on two dates, at commercial harvest and one week after this. Each of the 5 field blocks (which was usually one tree, with groups of trees used for lower yielding trees) was large enough to harvest 360 fruit on each date. This fruit was divided into 4 groups of 90 (90 fruit for each of 4 oil (+/-) by storage atmosphere (CA or Air) treatment combinations). Each group of fruit was dipped either in the canola oil mixture or water. These batches were then stored in separate tubs either under controlled atmosphere (2.5% O₂: 1% CO₂) or in air at 0°C. The final treatment conditions were: oil and CA, oil and no CA, water and CA or water and no CA. Each batch of 90 fruit was placed into bags of 30 fruit. After both harvests, within each tub there were 6 bags (of 30 fruit) randomly allocated to the 2 harvest dates by three different storage times used for each treatment: 2, 3 and 4 months for air storage and 3, 5 and 7 months for CA storage. In storage, the 5th field block was split into two and these 2 extra tubs allocated to blocks 3 and 4. After storage the fruit was moved to 20°C in air and ripened for 1 week before assessing for scald, firmness and colour.

Canola oil dipping procedure

500 ml of canola oil was mixed in a blender with 500 ml of water and 10 ml of Tween 80 at 20°C. This mixture was then made up to 50 L with water to give a final concentration of 1% canola oil. In the case of Packham’s Triumph pears a fungicide (Bavistan) was also added.

Dipping was carried out in a large plastic crate (approx 80 L volume). Fruit was contained in a smaller crate with holes in the base. This crate was submerged in the oil mixture or water for 30 seconds. Fruit was allowed to drain and dry naturally.

Statistical Analysis

Results were analysed using ANOVA, GenStat for Windows 5th edition (Lawes Agricultural Trust, IACR-Rothamsted) and significance determined using LSDs at the 5% level.

The LSD bars presented in the Figures are for the comparison of oil-treated fruit and control fruit. LSDs for other comparisons may vary and are not presented.

Where scald occurrence for both treatments was zero, the data was removed from the analysis. Where one treatment resulted in zero scald and the other did not, results were analysed by Fishers exact test.

9.2.2 Results

Red Delicious

Untreated apples stored in air began to show traces of scald after 3 months storage (Fig 9.1). After 4 months, both canola-treated and untreated fruit were affected by scald (between 5 and 19% of apples showing signs of scald). The most severely affected fruit were the commercial harvest/control fruit while the least affected were the late harvested/canola dipped fruit. However, no statistically significant difference was found between the oil and control treatments for the same harvest.

Oil treatment of fruit picked at commercial harvest and stored under CA for 7 months resulted in significantly less scald (Fig 9.1). The shorter storage times (3 and 5 months) showed either no scald or no significant reduction due to the treatment, but overall had significantly less scald than 7 months storage.

Neither oil nor storage time had any effect on fruit firmness, although CA stored fruit were firmer than air stored after 3 months (results not shown).
Figure 9.1 Effect of canola oil dipping, storage atmosphere and harvest date on the development of scald on Red Delicious apples harvested in the Yarra Valley. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.

Granny Smith

Granny Smith apples stored in CA did not develop scald within 3 months storage and only developed low levels (<10%) after 5 months storage regardless of harvest date or treatment. Fruit harvested at commercial maturity and stored for 7 months displayed significantly less scald when treated with canola oil than when left untreated. However, there was no significant difference for the late harvested fruit (Fig 9.2).

Air stored fruit showed that oil treatment led to significant decreases in scald occurrence for late harvested fruit at 2 (Fisher’s exact test P<0.001) and 3 months storage. Length of storage also played a major part in scald development with fruit stored for 2 months showing significantly less scald than 3 or 4 months storage.

After 7 months in CA, the commercially harvested Granny Smith apples that had been dipped in oil were significantly firmer than untreated. But in the majority of cases, retention of firmness was related to CA storage rather than air or to length of storage (results not shown).

Figure 9.2 Effect of canola oil dipping, storage atmosphere and harvest date on the development of scald on Granny Smith apples harvested in the Goulburn Valley. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.
Packham’s Triumph

Significantly less scald was observed in canola treated fruit than untreated fruit when harvested at commercial maturity and stored for 7 months in CA and 4 months in air (Fig 9.3).

The oil treatment had a positive effect on retaining firmness in 4 months air stored and 5 months CA stored late harvested fruit (results not shown).

It also maintained greenness in late harvested pears stored in CA for the shorter storage times (3 and 5 months) (Fig 9.4).

**Figure 9.3** Effect of canola oil dipping, storage atmosphere and harvest date on the development of scald on Packham’s Triumph pears harvested in the Yarra Valley. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.

**Figure 9.4** Effect of canola oil dipping, storage atmosphere and harvest date on the colour of Packham’s Triumph pears harvested in the Yarra Valley. Green = 180°, Yellow = 90°. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.
9.3 Alternative treatments - 2000 Season

9.3.1 Materials and Methods

Experimental Design

A small trial was undertaken to investigate the effect of some commercially available postharvest treatments on the development of superficial scald in Granny Smith apples.

The products tested were, 1% Canola oil, Synertrol Ag and Eco Super XL which contain canola oil and Citrox. These were applied by dipping at the recommended rate. The design used was a split-plot design as follows. Four replicates (blocks) of 90 fruit were used for each treatment. Each batch of 90 fruit within each block was dipped into one of the 3 products. Each batch was divided into 3 bags of 30 fruit and placed in a crate. Each bag was randomly allocated to be stored in air for 4, 5 or 7 months.

9.3.2 Results

None of the treatments successfully controlled scald to a commercially acceptable level during 4-7 months air storage, although the fruit treated with 1% canola and Synertrol developed significantly less scald than the untreated fruit after 4 and 5 months storage (Fig 9.5). In addition, the canola and Citrox treated fruit were significantly firmer and the canola treated fruit significantly greener than the untreated apples (Fig 9.6).

Figure 9.5 The effect of alternative postharvest treatments on the development of scald on Granny Smith apples. Error bar is LSD (P=0.05) for comparison of treatments.

Figure 9.6 The effect of alternative postharvest treatments on the firmness and greenness Granny Smith apples. Error bar is LSD (P=0.05) for comparison of treatments.
9.4 Organic Fruit - 2001 Season

Canola dipping to control scald may be of particular usefulness for organic production. During 2001, several trials were carried out using commercially grown and stored organic fruit.

9.4.1 Materials and Methods

Experimental Design

Three cultivars of organically grown fruit (Red Delicious and Granny Smith apples and Packham’s Triumph pears) were treated with 1% canola oil, as described in part 9.2.1. The design used was a randomised complete block design, as follows.

Packham’s Triumph pears were harvested on two dates (27/2 and 5/3) and Red Delicious apples on 5/3. Fruit was divided into 3 blocks. For each harvest three boxes of approximately 90 fruit were dipped in the canola oil emulsion and three boxes left as untreated controls. Fruit was divided into bags of approximately 45 fruit and stored under controlled atmosphere (1.5% O₂: 1% CO₂) at a commercial coolstore for 25 weeks and then transferred to IHD and stored in air at 0°C for a further 5 - 11 weeks before assessment (30 or 36 weeks).

Nine boxes (3 blocks of 3 boxes) of Granny Smith apples were harvested on 24/4 (late harvest). Three boxes each were treated with 1% and 6% canola oil and three boxes left untreated. The fruit was then placed in storage in air at 0°C. Half of the fruit was assessed at 5 months and half at 6.5 months.

Upon removal from storage the fruit was assessed for the presence of superficial scald as well as firmness, colour and internal browning.

Statistical analysis was performed as described in part 9.2.1.

9.4.2 Results

Packham’s Triumph

Packham’s Triumph pears treated with canola showed a reduction in the occurrence of superficial scald of between 4 -20%. This was statistically significant for fruit stored for both 30 weeks (Fishers exact test P<0.05) and 36 weeks, for both early and late harvests (Fig 9.7). Canola treated fruit developed no scald after 30 weeks storage.

Untreated fruit stored for 36 weeks showed significantly more scald than fruit stored for 30 weeks.

Oil treated fruit were firmer than control fruit, particularly the late harvested fruit stored for 30 weeks. There was no significant effect on colour (Fig 9.8).
**Figure 9.7** The effect of 1% canola oil on the occurrence of scald on organically grown Packham’s Triumph pears. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.

**Figure 9.8** The effect of 1% canola oil on the retention of firmness and greenness in organically grown Packham’s Triumph pears. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.
Red Delicious

Canola treated Red Delicious showed significantly less scald than untreated fruit after 36 weeks of storage. Both treated and untreated fruit showed a significant increase in scald between 30 and 36 weeks storage (Fig 9.9).

There was no significant change in firmness or internal browning due to the treatment.

![Organic Red Delicious (Canola/CA)](image)

**Figure 9.9** The effect of 1% canola oil on the occurrence of superficial scald on organically grown Red delicious apples. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.

Granny Smith

After 29 weeks of storage there was no superficial scald on any Granny Smith apples. This is likely to be due to a combination of the maturity of the fruit at harvest and growing conditions. This trial again demonstrated that delayed harvest is an effective strategy to reduce scald susceptibility of Granny Smith apples.

There was no significant difference due to the treatment in firmness, colour or internal browning. Both 1% and 6% canola oil caused no damage to the fruit.
9.5 Pears - 2001 Season

During 2001, it was decided to investigate further the effect of canola oil on pears, particularly with respect to maintaining firmness and greenness.

9.5.1 Materials and Methods

Experimental Design

Two cultivars of pears, WBC and Packham’s Triumph, from the Goulburn Valley were treated with 1% canola oil as described in part 9.2.1.

The design used was a randomised complete block design, as follows. For WBC pears, 5 replicates (blocks) of 40 fruit were dipped either in oil or in water (controls). Fruit was divided into bags of 20 fruit and were removed after 12 and 16 weeks storage in air at 0°C, and assessed for scald, colour, firmness and internal breakdown. Fruit was assessed for colour before going into storage, ex-store (as soon as removed from storage) and ex-market (after one week ripening at 20°C).

For Packham’s Triumph, 5 replicates (blocks) of 90 fruit were harvested. Groups of 30 fruit were dipped either in oil or in water (controls). Two oil treatments were used, new oil and old oil (oil from last season’s trials about a year old). It was thought that the old oil might have altered in storage due to the breakdown of vitamins or oxidation of fatty acids. Fruit was placed under controlled atmosphere (2.5% O₂ and 1% CO₂) at 0°C and assessed after 8 months for scald, firmness, colour and internal breakdown.

Statistical analysis was performed as described in part 9.2.1.

9.5.2 Results

WBC pears treated with 1% canola oil showed significantly lower incidence of superficial scald than untreated fruit when stored for 12 or 16 weeks in air, although overall control was poor.

Early harvested Packham’s Triumph pears showed a significant reduction in scald occurrence after canola oil treatment. Late harvested fruit had no significant reduction in scald due to the treatment, although in general the later picked fruit had lower levels of scald than early fruit (Fig 9.10).

Figure 9.10 The effect of canola oil dipping on scald development on WBC and Packham’s Triumph pears. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.
Upon removal from storage, the canola-dipped WBC pears stored for 12 weeks were significantly greener than the untreated fruit, but there was no difference between treated and untreated fruit after 16 weeks storage. After ripening for 1 week at 20°C treated fruit were significantly more green than untreated fruit at both storage times.

Late harvested Packham’s Triumph fruit treated with “new” oil were significantly greener than control fruit or fruit treated with “old” oil. The colour of fruit treated with “old” oil was not significantly different to that of the controls. Early harvested fruit showed no reduction in yellowing due to either oil treatment (Fig 9.11).

**Figure 9.11** The effect of canola oil dipping on colour development of WBC and Packham’s Triumph pears. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.
After both 12 and 16 weeks storage, treated WBC pears were significantly firmer than the controls.

Late harvested Packham’s were significantly firmer than control fruit when treated with “new” oil. Early harvested fruit showed no reduction in softening due to either oil treatment (Fig 9.12).

**Figure 9.12** The effect of canola oil dipping on firmness of WBC and Packham’s Triumph pears. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.
9.6 Stripped oil - 2001 Season

Stripped oil is oil which has had the \( \alpha \)-tocopherol (vitamin E) and other related compounds removed. Although a naturally occurring anti-oxidant found in apples it has been demonstrated (Anet and Coggiola, 1977) that when applied as a dip \( \alpha \)-tocopherol acts as a pro-oxidant. There has been some indication in recent publications that stripped oil gives a greater degree of scald protection than normal oil. Ju et al. (2000) found that a number of stripped plant oils controlled scald as effectively as DPA whereas the unstripped oils did not.

9.6.1 Materials and Methods

Experimental Design

Two cultivars of scald susceptible apples, Lady William from Harcourt and Granny Smith from the Yarra Valley were treated using either 1% commercially available canola oil, 1% “stripped” oil or water.

The design was a randomised complete block design, as follows. Five blocks of 150 fruit were harvested. Five groups of 50 fruit were dipped for each treatment. The apples were divided into bags of 25 fruit and stored under controlled atmosphere (2.5%O\(_2\): 1%CO\(_2\)) at 0°C for 2 storage periods. Fruit was removed from storage after 5 or 6 months (Granny Smith) or 7 and 8 months (Lady William). After ripening for one week at 20°C apples were assessed for scald, firmness, colour and internal breakdown.

Statistical analysis was performed as described in part 9.2.1.

Making Stripped Oil

Stripped oil preparation and analysis was carried out by the State Chemistry Laboratories, Werribee, Victoria.

The stripped oil was prepared according to a method adapted from Khan and Shahidi (1999). Canola oil diluted 1:1 with hexane was passed through a multilayered chromatographic column. The 500 ml column was packed with four adsorbents: 40 g activated silicic acid; 20 g of 1:2 Celite 545: activated charcoal; 80 g of 1:2 Celite 545: powdered sugar; and 40 g activated silicic acid. The column was attached to a water vacuum pump and the eluted oil and hexane mixture collected. This mixture was put through a rotary evaporator for approximately 30 minutes at 40°C to remove the hexane. The separated oil was dried with nitrogen to eliminate any remaining hexane.

100 ml fractions of stripped oil were collected and analysed for tocopherol content by gas chromatography. Only the first 100 ml showed significant reduction in tocopherol content. The stripping process removed gamma and delta tocopherols, in addition to \( \alpha \)-tocopherol.

<table>
<thead>
<tr>
<th>Tocopherol (mg/100g)</th>
<th>alpha</th>
<th>gamma</th>
<th>delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh oil</td>
<td>23</td>
<td>36</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Fraction 1</strong></td>
<td><strong>0.1</strong></td>
<td><strong>9</strong></td>
<td><strong>0.1</strong></td>
</tr>
</tbody>
</table>

Oil used to treat Granny Smith contained —

<table>
<thead>
<tr>
<th>Tocopherol (mg/100g)</th>
<th>alpha</th>
<th>gamma</th>
<th>delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh oil</td>
<td>&lt;0.1</td>
<td>4</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td><strong>Fraction 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
9.6.2 Results

The canola-treated Granny Smith fruit developed somewhat less scald than the untreated fruit, but it was not statistically different (Fig 9.13).

The Lady Williams apples stored for 7 months showed no significant reduction in scald due to either of the oil treatments. The fruit stored for 8 months showed a significant reduction in scald occurrence due to the stripped oil but not the normal oil. (Fig 9.13).

Overall there was no significant difference in effectiveness found between stripped and normal oil.

Granny Smith fruit treated with stripped oil and stored for 5 months were significantly greener than the control fruit (Fig 9.14).

The firmness of either cultivar was not affected by oil treatment.

---

**Figure 9.13** The effect of stripped and whole canola oil on the development of scald on Granny Smith and Lady William apples. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.

**Figure 9.14** The effect of stripped and whole canola oil on the colour development of Granny Smith apples. Error bar is LSD (P=0.05) for comparison of canola treated and untreated.
9.7 Discussion

Treatment with 1% canola oil achieved some scald reduction on Red Delicious, Granny Smith and Lady William apples and Packham’s Triumph pears, but not enough to be acceptable commercially. Canola oil treatments could possibly be useful in achieving zero scald after short term storage when untreated fruit are beginning to show a few percent of scalded fruit.

Higher concentrations of other plant oils have been reported to control scald in Red Delicious fruit (Ju et al. 2000). However higher concentrations of canola oil have previously caused damage in CA, possibly due to modification of the internal atmosphere resulting in low oxygen injury. The benefit of oil is more pronounced on more mature fruit. The combination of late harvest and canola oil, or late harvest alone should be considered by organic growers wishing to store fruit.

We do not know why the stripped oil was not more effective than regular oil in our experiments when Ju et al (2000) showed a dramatic difference. Possibly because treatment was delayed for 1-2 weeks after harvest it was less effective than it could have been. It would be useful to investigate stripped oils further applying directly after harvest.

The ‘new’ oil was somewhat more effective in maintaining storage quality but did not improve scald control.

In pears it could be useful as a treatment to delay ripening, which may be of benefit in some markets where hard, green pears are preferred. The effectiveness of the oil for this purpose is somewhat dependent on both storage length and the maturity of the fruit at harvest.
10. CONCLUSION

Of the five alternative scald management strategies investigated here both 1-MCP and ultra low oxygen storage provided good scald control while maintaining the quality of the fruit. 1-MCP shows promise for storing fruit scald free for up to 12 months, while ULO was effective for the first 6 months of storage.

An application for registration of 1-MCP (marketed as ‘Smartfresh’ by Rohm and Haas) for use on apples and pears in Australia is likely to be submitted in the next year. Further work on different cultivars of apples and pears to determine appropriate treatment levels and to investigate eating quality of the fruit needs to be undertaken.

Scald forecasting, including the use of optimum harvest dates and storage times, and ULO, are the most effective ‘non-chemical’ methods of controlling scald. Scald forecasting is a useful tool in deciding the type and level of treatment needed for a particular crop. While the predictive models need further refinement for some cultivars, good preliminary models have been developed for Red Delicious, Granny Smith and Pink Lady from various areas.

ULO, while very effective, requires well sealed coolrooms which may require considerable upgrading of existing infrastructure. There would also be an increased cost to generate the lower oxygen and carbon dioxide levels involved. As there is a risk of low oxygen injury to some cultivars, extremely low oxygen is not recommended, and careful monitoring would be required.

Alcohol fumigation, using both ethanol or propanol, was effective for Granny Smith, Pink Lady and Packham’s Triumph, but treatment levels need to be determined which are effective against scald but do not result in off flavours or changes in texture. Initially, it was found that excise tax made the ethanol treatment very costly, but if a denaturant is added to prevent it being consumed directly the tax may be avoided.

Canola oil provided some extension of storage time and reduction of scald and may be useful in areas where chemical control is not allowed. It could be applied using existing systems. In some cases the oil treatment delayed yellowing and softening of pears which is highly desirable for pears exported to South-east Asia.

Commercial application of either canola oil or alcohol will require regulatory approval even though both compounds are consumed as food.

If the scald forecasting models were implemented, fruit could be left untreated if marketed within the calculated scald free period, which ranges between 3 to 9 months. Fruit determined to have low susceptibility could be treated with reduced rates of DPA, possibly in combination with other treatments such as ULO for longer term storage. Only the less mature fruit and the most scald susceptible varieties need to be treated as usual. This would lead to decreased chemical costs for growers and reduction of DPA residues. Current problems with the disposal of used DPA will also be reduced, minimising costs and the impact on the environment. Also, avoiding wetting of fruit could lessen the development of postharvest rots and thus reduce the need for fungicide application.
11. TECHNOLOGY TRANSFER

11.1 Publications


A report was submitted for the annual AAPGA conference, August 2001.

An article was submitted for the 2001-2002 Apple and Pear Industry report.

11.2 Meetings and Presentations


In February and March 2002 research findings were presented to interstate collaborators in Batlow and Huonville. Meetings were held with a number of key growers and coolstore operators in the Huonville area.

Goulburn Valley Orchard and Vineyard IPM Field day, October 29, 2002.

AAPGA Research Providers Meeting, August 11, 2000, Shepparton.

11.3 Implementation

Several on farm trials, storing untreated/DPA free fruit, were initiated in 2002 to test the feasibility of scald forecasting under commercial conditions.

The largest trial took place in Batlow where 27 bins of Red Delicious were left untreated and samples sent to IHD for assessment.

Boxes of untreated Granny Smith, Pink Lady and Red Delicious apples were also stored commercially at several orchards in Victoria.

In December 2002 and January 2003 planning meetings were held with Ron Gordon (Batlow Fruit Co-op) to discuss further implementation of the results, particularly scald forecasting and the feasibility of reducing DPA on fruit for short term storage, ultra low oxygen storage and 1-MCP.

11.4 Further research

Further research is planned for the 2003 season in collaboration with the Batlow Fruit Co-op to investigate ultra low oxygen storage of Red Delicious and Pink Lady apples in combination with reduced rates of DPA.
12. RECOMMENDATIONS

The scald forecasting trials have shown that many varieties have a considerable scald free period when left untreated. Some varieties such as Gala did not develop any scald over the course of the project when stored for up to 8 months, whilst other cultivars remained scald free for between 3 and 6 months. Findings in this project have demonstrated the potential use of scald forecasting as an alternative method of scald control. Many issues still require consideration and future research should focus on:

- Further development and refinement of existing scald forecasting models for Pink Lady, Red Delicious and Granny Smith cultivars.
- For some other cultivar and district combinations, such as Fuji in Tasmania and Red Delicious in Batlow, potentially useful forecasting models can be developed once at least two more years of scald incidence data is obtained.
- Determining the DPA rate reductions possible for specific cultivars based on predicted scald susceptibility at harvest.
- Development of forecasting models for pears based on firmness and preharvest hours eg. Packham’s Triumph, particularly for potential use by organic growers.
- Development of a decision-tree/calculator for grower use based on the final models developed for each cultivar in the form of a simple-to-use spreadsheet program.

It would be beneficial for growers to conduct their own on-farm trials, leaving a small number of bins undipped, in order to ascertain the risks of scald developing under their individual circumstances. This could ultimately lead to a larger proportion of fruit for early and mid-term marketing remaining untreated, reducing the costs of DPA and fungicides and the need for drench disposal.

Ultra low oxygen was very effective in controlling scald for the first 6 months of storage. It requires that rooms to be well sealed and growers considering constructing new stores or upgrading existing stores should consider making them capable of ULO. Due to the risks of low oxygen injury fruit under ULO storage would need to be carefully monitored and ways of doing this would need to be assessed.

Both scald forecasting and ULO could be used with reduced rates of DPA for medium-term and long-term storage. This would reduce the likelihood of excessive residues.

1-MCP provided excellent control of superficial scald on both Granny Smith and Red Delicious apples. Further work is needed to demonstrate its effectiveness, and to develop practical delivery methods, under commercial conditions. The effect on eating quality of the fruit also needs to be investigated once registration is obtained. Further work, to determine effectiveness and treatment levels, on other cultivars of apples and pears is also recommended.

Canola oil, while not controlling scald to commercially acceptable levels, did provide some reduction in scald and an increase in shelf life (firmness and greenness during marketing) especially for the pear varieties Packham’s Triumph and WBC. Organic growers should seriously consider this treatment to extend storage and improve appearance of pears.

While alcohol fumigation provided good scald control using both ethanol and propan-1-ol, a high degree of flavour tainting was observed in all cultivars except Granny Smith. Propan-2-ol did not produce any off flavours and further research is needed to ascertain if higher treatment levels will control scald without tainting the fruit. Combinations of ethanol and propan-2-ol should also be further investigated, as these may be more effective than ethanol alone, and would be able to be used without the addition of a denaturant.

Over the past decade the pome fruit industry and Government have invested in research projects in the areas of scald control, DPA residue management, postharvest rot control and maturity assessment, market access and environmental issues. These have resulted in various technologies and new information that if implemented by industry will potentially improve
productivity, reduce production costs and ensure continued export market access. However, the transfer of outcomes has been limited by the time and budget constraints of those projects.

Further investment in the extension of these outcomes to growers is necessary. Practical training for growers and packers and assisting growers in testing new technology would reduce the risks associated with change of practice and improve the likelihood of adoption.
13. ACKNOWLEDGMENTS

This study was jointly funded by Horticultural Australia Ltd, Apple and Pear Australia Ltd and the Department of Primary Industries, Victoria. Rohm and Haas Pty. Ltd. provided a voluntary contribution in 2001/02.

The following individuals are also acknowledged for their contribution to the project:

Craig Trenerry and Phil Zeglinski (State Chemistry Laboratories, Werribee) for their assistance in manufacturing stripped canola oil.

Janyce Truett and Pam Rogers (IHD, Knoxfield) for their providing and maintaining the controlled atmosphere and cold room requirements. And Janyce for her invaluable knowledge and help with the gas chromatography.

Thanks also to Plant Standards, Victoria, for permitting the interstate movement of apples used in the experiments.

All of the growers who kindly allowed us to harvest fruit and conduct trials on their properties.
14. BIBLIOGRAPHY


Huelin F E, Coggiola I M (1968) Superficial scald, a functional disorder of stored apples IV- Effect of variety, maturity, oiled wraps and diphenylamine on the concentration of α-farnesene in the fruit. *Journal of the Science of Food and Agriculture* 19, 297-301.


Sisler E C, Serek M (1997) Inhibitors of ethylene responses in plants at the receptor level: Recent developments. *Physiologia Plantarum* 100, 577-582.


