

**Project title:** Modulating the storage temperature for Cox apples for improved quality and control of rotting (Years 1-2)  
Modulating the storage temperature for Braeburn apples for improved quality (Year 3)

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**AUTHENTICATION**

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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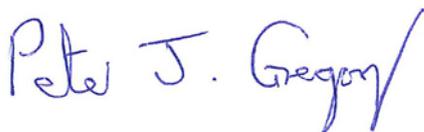
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# **GROWER SUMMARY**

## **Headline**

Modulating storage temperatures of Cox and Braeburn below the current recommendations does not improve fruit quality.

## **Background and expected deliverables**

### ***Cox (Project Years 1-2)***

Cox remains the most important dessert apple variety in the UK, despite its susceptibility to a range of physiological disorders and fungal rots. The firmness of the stored fruit at the point of sale is often marginal in relation to specifications laid down by the multiple retailers, despite harvesting at the correct stage of maturity and providing optimum storage conditions. Although the use of 1-MCP (SmartFresh™) has helped significantly to delay softening during storage and shelf-life, care must be taken when it is used on fruit destined for post-January storage due to a heightened risk of core flush. This project addresses the need to supply consumers with Cox of consistent quality from September until March, and to minimise the wastage incurred by growers due to the development of fungal rots.

Current levels of wastage are often unacceptable and there is limited scope for chemical intervention to ameliorate the problem, although use of rot risk assessment can assist in management of rots and minimize losses. There are currently no fungicides permitted for post-harvest application to apples in the UK. Fungicides applied pre-harvest for rot control usually result in detectable residues in the fruit at harvest and are still present after cold storage.

Reducing the temperature for Controlled Atmosphere (CA)-stored Cox provides an opportunity to improve fruit quality, particularly firmness, and to reduce rot development. However, it is imperative that these benefits are achieved without inducing low temperature breakdown (LTB) symptoms in the fruit. Although climate change means that there is a greater likelihood of warmer growing seasons in the future and consequently a reduced susceptibility to LTB, it is unlikely that Cox will tolerate a lower storage temperature for the entire storage period. However, modulating the store temperature to provide shorter periods at lower temperatures may provide the benefits required without inducing LTB in the fruit. This approach

has proved successful for other chilling-sensitive varieties in work done abroad (such as cv. McIntosh in Canada). The objective of this project was to develop a strategy for modified temperature management of commercial Cox stores in the UK that would include the use of 1-MCP (SmartFresh™).

### ***Braeburn (Project Year 3)***

With increasing volumes of Braeburn being planted, there is a need to extend the storage life of fruit to modulate the supply of fruit onto the UK market. Braeburn is a variety that maintains good texture and eating quality, but storage is often storage terminated prematurely because of internal physiological disorders. The high density of Braeburn apples gives rise to poor gas diffusion properties leading to the accumulation of internal CO<sub>2</sub> and depletion of oxygen (hypoxia). Establishing CA conditions too rapidly can lead to symptoms of flesh browning early in the storage season, referred to as Braeburn Browning Disorder (BBD). A second distinct condition known as late-season core-flush is associated with a pink/brown discolouration of the flesh surrounding the core cavity and its severity increases with the length of CA storage. Harvesting over-mature fruit, establishing CA conditions too rapidly or storing at too low a temperature for prolonged periods can exacerbate the condition.

However, introduction of shorter periods of intermittent low-temperature (0.5-1.0°C) or delayed ethylene scrubbing into a standard CA Braeburn regime (1.2% O<sub>2</sub>, <1% CO<sub>2</sub> at 1.5-2.0°C) may help to reduce the overall respiration rate of fruit, preventing a localised depletion of oxygen in the core region that often leads to damage. The objective of this project was to investigate the use of modulated storage temperatures or delayed ethylene scrubbing during CA storage of Braeburn to improve fruit quality and possibly extend the storage life of Braeburn.

## **Summary of the project and main conclusions**

### ***Cox (Year 1)***

Cox apples were harvested on 2 September 2009 from an 11 year-old Cox orchard planted on M9 rootstock. Maturity measurements (Firmness, Colour, Starch, % Brix and internal ethylene concentration) were made on the day of harvest. Apples were cooled to 3.5°C overnight.

The day following harvest, half the fruits were treated with SmartFresh™ (625 ppb) at 3.5°C for 24 hours whilst the untreated fruit were kept in a separate store at 3.5°C. Subsequently, half of the SmartFresh™-treated and untreated fruit were inoculated with *Nectria*. This provided a total of four post-harvest treatment combinations: untreated/uninoculated, SmartFresh™/uninoculated, untreated/*Nectria* and SmartFresh™/*Nectria*.

Four boxes each containing one of the treatment combinations were loaded into each of eight storage cabinets and flushed with nitrogen to 1.25% O<sub>2</sub>. Four cabinets were maintained at 3.5°C and four at 1.5°C. Every two months, the fruit were moved between cabinets at the two temperatures so that eight temperature regimes were tested, as shown in Table 1.

**Table 1.** Temperature regimes assessed during the Cox storage trials

| Treatment | 0 – 60 days | 60 – 120 days | 120 – 180 days |
|-----------|-------------|---------------|----------------|
| 1         | 3.5-4°C     | 3.5-4°C       | 3.5-4°C        |
| 2         | 1.5-2°C     | 3.5-4°C       | 3.5-4°C        |
| 3         | 1.5-2°C     | 1.5-2°C       | 3.5-4°C        |
| 4         | 1.5-2°C     | 1.5-2°C       | 1.5-2°C        |
| 5         | 3.5-4°C     | 1.5-2°C       | 3.5-4°C        |
| 6         | 3.5-4°C     | 1.5-2°C       | 1.5-2°C        |
| 7         | 1.5-2°C     | 3.5-4°C       | 1.5-2°C        |
| 8         | 3.5-4°C     | 3.5-4°C       | 1.5-2°C        |

Fruits were inspected ex-store and after 1 week's shelf-life at 20°C in November, January and March.

Continuous low temperature storage reduced the rate of softening but caused significant amounts (30%) of LTB in long-term stored Cox. The incidence of LTB increased to 60% when continuous low temperature storage was used on SmartFresh™-treated fruit. Shorter periods of low-temperature used at the beginning of the storage period had a small effect on reducing the degree of softening and did not induce LTB in non-SmartFresh™-treated fruit. LTB was observed on SmartFresh™-treated Cox but was less severe than found in continuous low temperature storage.

The incidence of *Nectria* rots was reduced with SmartFresh™ when combined with storage at 1.5°C. SmartFresh™-treated Cox that received at least 4 months at 1.5°C had less rots. Interestingly, SmartFresh™ did not affect the incidence of rotting when Cox was stored at 3.5°C for the whole period. Rotting in untreated Cox was more variable and no clear trend in temperature regime was evident; however, fruit stored for the whole storage period at 1.5°C had the lowest incidence of rots.

### **Cox (Year 2)**

Cox apples were harvested on three occasions: 6, 13 and 20 September 2010 from a 12 year-old Cox orchard planted on M.9 rootstock. Maturity measurements (Firmness, Colour, Starch, % Brix and internal ethylene concentration) were made on the day of harvest. Apples were cooled to 3.5°C overnight.

After cooling fruit to store temperature, half the fruit was treated with SmartFresh™ (625 ppb) at 3.5°C for 24 hours whilst the untreated fruit were kept in a separate store at 3.5°C.

Subsequently, half of the SmartFresh™-treated and untreated fruit were inoculated with *Nectria*. This provided a total of four post-harvest treatment combinations: untreated/uninoculated, SmartFresh™/uninoculated, untreated/*Nectria* and SmartFresh™/*Nectria*.

Two replicate cabinets were used for each temperature combination. A box of SmartFresh™-treated and untreated Cox from each pick were placed in each cabinet. In addition, netted samples of inoculated fruit were added to each cabinet. After loading, cabinets were flushed with nitrogen to 1.25% O<sub>2</sub>. During the initial two month storage period six cabinets were maintained at 3.5°C and four at 1.5°C. Every two months, fruit was moved between cabinets at the two temperatures so that five most promising temperature regimes from year 1 were tested in year 2. These are detailed as Table 2.

**Table 2.** Temperature regimes assessed during the Cox storage trials

| <b>Treatment</b> | <b>0 – 60 days</b> | <b>60 – 120 days</b> | <b>120 – 180 days</b> |
|------------------|--------------------|----------------------|-----------------------|
| 1                | 3.5-4°C            | 3.5-4°C              | 3.5-4°C               |
| 2                | 3.5-4°C            | 3.5-4°C              | 1.5-2°C               |
| 3                | 3.5-4°C            | 1.5-2°C              | 1.5-2°C               |
| 6                | 1.5-2°C            | 1.5-2°C              | 3.5-4°C               |
| 7                | 1.5-2°C            | 3.5-4°C              | 3.5-4°C               |

Cox were inspected ex-store in November, January and March. Additional assessments were made after 1 week's shelf-life at 18°C following each inspection.

The 2010/11 season was not a high risk year for LTB or core flush in Cox. Consequently no symptoms of either disorder appeared in Cox during periods of low-temperature storage. No benefit of improved firmness retention was accrued by incorporating periods of low-temperature storage. Extending the length of storage at low temperature to 4 months out of 6 increased physiological stress. Although no internal physiological disorders were visible, sub-clinical damage caused by prolonged exposure to low-temperatures resulted in elevated respiration rates leading to greater rates of fruit softening. SmartFresh™-treated fruit remained firm throughout the 6-month storage period and although late picked fruit (pick 3) were marginally softer, SmartFresh™ treatments maintained firmness retention above commercial threshold of acceptable firmness. Non-treated Cox harvested from picks 1 and 2 and stored under standard 3.5°C temperature condition maintained firmness above 65 N for the full six months storage period. Pick 3 fruit only lasted 60 days before firmness values dropped below 65 N.

Reducing storage temperatures to 1.5°C earlier in the storage life reduced the incidence of *Nectria* rots, while lowering storage temperatures between January and March had less impact on rot development.

In conclusion, low-temperature storage was able to reduce the incidence of *Nectria* rotting, however, the heightened risk of internal damage, precluded this treatment as a practical method of rot control.

SmartFresh™ was able to improve firmness retention during storage and was particularly effective on early picked fruit. Delaying the harvest date led to a progressive loss of firmness during storage in untreated fruit. However, firmness retention was improved in late picked fruit by the application of SmartFresh™ at harvest. Low-temperature storage was not a suitable alternative to Smartfresh™ in maintaining fruit quality during extended storage.

### ***Braeburn (Year 3)***

Braeburn apples from six orchards, comprising four Hilwell and two Lochbuie clones were picked on the week beginning 4 October. Storage samples were cooled for 48 hours, before a holding CA of 2% O<sub>2</sub> was established by respiration and maintained for 10 days. The final storage CA regime of 1.2% O<sub>2</sub> was then established through fruit respiration. Fruit was subject to periods of modulated temperature (Table 3) each lasting 70 days of either a standard (1.5-2°C) or low temperature regime (0.5-1.0°C). Delayed ethylene scrubbing was applied by placing 5 kg bags of potassium permanganate coated clay beads into selected cabinets after the first 70 days of storage.

Braeburn was harvested at the optimum commercial maturity, when fruit background red colour had reached 50% coverage with 80% starch content. However, considerable variation in physiological maturity was observed within the 6 orchard sites. Internal ethylene exhibited a range from 77 ppb to 538 ppb and starch clearance patterns ranged from 3-5 on the CTIFL scale. Moreover, fruit respiration varied from 5.3-7.4 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>. Fruit sugar content (% Brix) was related to the dry matter content of fruit at harvest rather than related to fruit maturity. The range of maturities of fruit at harvest was reflected in the quality of fruit during storage.

**Table 3.** Temperature regimes assessed during the Braeburn storage trials 2011-2012

| Treatment | 0 – 70 days | 70 – 140 days | 140 – 210 days |
|-----------|-------------|---------------|----------------|
| 1         | 1.5-2°C     | 1.5-2°C       | 1.5-2°C        |
| 2         | 1.5-2°C     | 1.5-2°C       | 0.5-1°C        |
| 3         | 1.5-2°C     | 0.5-1°C       | 0.5-1°C        |
| 4         | 0.5-1°C     | 1.5-2°C       | 1.5-2°C        |
| 5         | 0.5-1°C     | 0.5-1°C       | 1.5-2°C        |
| 6         | 0.5-1°C     | 0.5-1°C       | 0.5-1°C        |
| 7*        | 1.5-2°C     | 1.5-2°C       | 1.5-2°C        |
| 8*        | 0.5-1°C     | 0.5-1°C       | 0.5-1°C        |

\* Delayed ethylene scrubbing after 70 days

Orchards that were more mature at harvest were prone to developing core-flush and Braeburn Browning Disorder (BBD). Fruit with respiration rates above 6 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> resulted in a greater incidence of internal disorders.

Fruit firmness remained high (70-90 N) in all orchard consignments after 7 months storage and only limited softening was evident after shelf-life conditioning. Storage at lower temperatures had little influence on firmness, retention of green background or the incidence of internal physiological disorders. Fruits subjected to lower temperature (0.5-1.0°C) storage at the beginning of the storage season were under greater physiological stress leading to higher concentrations of ethylene in the storage atmosphere.

The addition of delayed ethylene scrubbing reduced the loss of background green colour that occurred late in the storage season in orchard consignments that were over mature entering storage. The effect of ethylene scrubbing on controlling core-flush and Braeburn Browning Disorder was undetermined due to the large variation in the incidence between orchard consignments and treatment effects.

## Conclusions

Incorporating periods of lower temperature (1.5-2.0°C) into the standard 6 month storage period for Cox's Orange Pippin reduced the incidence of *Nectria* rots. However, improvements in fruit quality were limited and modulating the temperature did not reduce the risk of low temperature breakdown (LTB).

Modulated low temperature storage (0.5-1.0°C) of Braeburn reduced the rate of softening in fruit from some orchard consignments, but failed to control the development of internal disorders.

### **Financial benefits**

No financial benefits were identified from this research project.

### **Action points for growers**

- Modulating storage temperatures of Cox and Braeburn below current recommendations does not improve fruit quality.
- Harvesting fruit at optimum harvest maturity is critical for maintaining fruit quality during long-term storage. With Braeburn, the standard practice of waiting for fruit to reach 50% red colour can result in harvesting fruit of sub-optimum harvest quality that has a greater potential of developing late-season core-flush and Braeburn Browning Disorder.
- Better indicators of harvest maturity for late season varieties such as Braeburn are needed.

## SCIENCE SECTION

### Introduction

#### Cox

Cox remains the most important dessert apple cultivar in the UK despite the increasing volumes of newer cultivars. Amongst its problems is its susceptibility to a range of physiological disorders and fungal rots. The firmness of the stored fruit at the point of sale is often marginal in relation to specifications laid down by the multiple retailers, despite harvesting at the correct stage of maturity and providing optimum storage conditions. Although the use of 1-MCP (SmartFresh™) has helped significantly in delaying softening during storage and shelf-life, care must be taken when it is used on fruit destined for post-January storage due to a heightened risk of core flush. The project addresses the need to supply consumers with Cox of consistent quality from September until March and to minimise the wastage incurred by growers due to the development of fungal rots. Current levels of wastage are often unacceptable and there is limited scope for chemical intervention to ameliorate the problem, although use of rot risk assessment can assist in management of rots and minimise losses (Cross & Berrie, 2010). Currently there are no fungicides permitted for post-harvest application to apples in the UK. Fungicides applied pre-harvest for rot control usually result in detectable residues in the fruit at harvest.

Reducing the temperature for Controlled Atmosphere (CA) -stored Cox provides an opportunity to improve fruit quality, particularly firmness, and to reduce rot development. However, it is imperative that these benefits are achieved without inducing low temperature breakdown (LTB) symptoms in the fruit. Although climate change means that there is a greater likelihood of warmer growing seasons in the future and consequently a reduced susceptibility to LTB it is unlikely that Cox will tolerate a lower storage temperature for the entire storage period. However modulating the store temperature to provide shorter periods at lower temperatures may provide the benefits required without inducing LTB in the fruit. This approach has proved successful for other chilling-sensitive cultivars such as the cv. McIntosh in Canada (Levesque *et al.*, 2006). The objective of this project was to develop a strategy for modified temperature management of commercial Cox stores in the UK that would include the use of 1-MCP (SmartFresh™).

## ***Braeburn***

With increasing volumes of Braeburn being planted there is a need to extend the storage life of fruit to modulate the supply of fruit onto the UK market. Braeburn is a variety that maintains good texture and eating quality, but often storage is terminated prematurely because of internal physiological disorders. The high density of Braeburn apples gives rise to poor gas diffusion properties, leading to the accumulation of internal CO<sub>2</sub> and depletion of oxygen (hypoxia). Establishing CA conditions too rapidly can lead to symptoms of flesh browning early in the storage season and is referred to as Braeburn Browning Disorder (BBD). A second distinct condition known as late-season core-flush is associated with a pink/brown discolouration of the flesh surrounding the core cavity and its severity increases with the length of CA storage. Harvesting over-mature fruit, establishing CA conditions too rapidly or storing at too low a temperature for prolonged periods can exacerbate the condition. However, introduction of shorter periods of intermittent low-temperature (0.5-1.0°C) or delayed ethylene scrubbing into a standard CA Braeburn regime (1.2% O<sub>2</sub>, <1% CO<sub>2</sub> at 1.5-2.0°C) may help to reduce the overall respiration rate of fruit, preventing a localised depletion of oxygen in the core region that is often associated with damage. The objective of this project was to investigate the use of modulated storage temperatures or delayed ethylene scrubbing during CA storage to improve fruit quality and possibly extend the storage life of Braeburn.

### **Overall aim of project**

To improve the quality and reduce wastage due to fungal rots and physiological disorders in Cox and Braeburn apples in long-term CA storage by modulating the storage temperature during CA storage and reduction in ethylene synthesis in fruit by the application of 1-MCP (SmartFresh™) or delayed ethylene scrubbing (Braeburn).

### ***Specific Objectives***

1. To investigate the use of modulating store temperature to achieve higher quality and lower rotting in CA-stored Cox and a reduced incidence of core-flush and flesh browning disorders (BBD) in Braeburn
2. To assess the impact of 1-MCP (SmartFresh™) on sensitivity of Cox apples to chilling and susceptibility to rotting, within the storage strategies tested.
3. To assess the impact of delayed ethylene scrubbing on the incidence of physiological disorders of long-termed stored Braeburn

4. To develop an improved commercial strategy for modified temperature management of Cox and Braeburn stores

## Materials and methods

### **Cox (Year 1)**

Cox apples were harvested on 2 September 2009 from plot EE190 at East Malling Research. The orchard was planted in 1998 and trees were grown on M9 rootstock at a spacing of 1,632 trees/ha (rows 3.5 m, trees 1.75 m in row). Fruit were sampled randomly and bruised, damaged and misshapen fruits were discarded from the trial.

Harvest maturity measurements were made on a subset of fruit (20). Firmness was measured using a motorised penetrometer (LRX). Colours were determined using a Hunter-lab colourmeter (LAB), soluble solids (% Brix) were measured using a digital refractometer. Fruits were cut at the equator and the calyx end to assess for internal disorders. A second sub-set of fruit (20) was sent for mineral analysis (FAST Ltd).

Apples were cooled overnight to 3.5°C and placed in 360 L cabinets: half the fruit were treated the following day with SmartFresh™ (625 ppb) for 24 hours at 3.5°C, before the atmosphere was exhausted. The remaining non-SmartFresh™-treated fruit were kept at 3.5°C overnight in a separate store.

Six isolates of *Nectria galligena* previously obtained from wood cankers or fruit rots were grown on Snay medium under UV lights for one week at ambient temperature to encourage spore (conidia) production. Fungal cultures were then scraped and rinsed with distilled water into a flask to prepare a spore suspension which was made up to 5 litres. Spore concentration (conidia) was checked on a haemocytometer.

The day following SmartFresh™ treatment sub-samples of 40 fruit of SmartFresh™ treated fruit and untreated fruit were dipped in a fungal spore solution containing  $3.7 \times 10^{-3}$  *Nectria* spores per mL for 1 min. the sub-samples of 40 fruit were placed in nets in plastic bags and the fruit left overnight to incubate at ambient temperature and high humidity to allow the *Nectria* conidia to germinate and infect fruit. The next day fruit were placed into eight storage cabinets. Each cabinet represented a single temperature regime and contained both SmartFresh™ and non-SmartFresh™-treated fruit. The storage atmosphere was flushed to 1.2% with nitrogen and external lime-scrubbers were used to remove CO<sub>2</sub>.

During the initial two month storage period, four temperature regimes were maintained at 1.5-2°C while the other four regimes were maintained at 3.5-4°C (Table 2.1). The contents of the chambers were moved between temperatures after 60 and 120 days as shown in Table 1.1. Fruits were assessed every two months, for firmness, colour, % Brix and for the presence of external and internal disorders. Respiration measurements were made on two replicate 20 fruit subsamples.

At the end of the storage period on 25 March the netted fruit samples of inoculated fruit were assessed for incidence of rots. Fruit was scored for the presence or absence of *Nectria* rots. Sound fruit was left at ambient temperature for seven days and then reassessed for *Nectria* rots. Uninoculated control fruit was assessed for rots at the same time.

**Table 1.1.** Temperature regimes assessed during the Cox storage trials

| <b>Treatment</b> | <b>0 – 60 days</b> | <b>60 – 120 days</b> | <b>120 – 180 days</b> |
|------------------|--------------------|----------------------|-----------------------|
| 1                | 3.5-4°C            | 3.5-4°C              | 3.5-4°C               |
| 2                | 1.5-2°C            | 3.5-4°C              | 3.5-4°C               |
| 3                | 1.5-2°C            | 1.5-2°C              | 3.5-4°C               |
| 4                | 1.5-2°C            | 1.5-2°C              | 1.5-2°C               |
| 5                | 3.5-4°C            | 1.5-2°C              | 3.5-4°C               |
| 6                | 3.5-4°C            | 1.5-2°C              | 1.5-2°C               |
| 7                | 1.5-2°C            | 3.5-4°C              | 1.5-2°C               |
| 8                | 3.5-4°C            | 3.5-4°C              | 1.5-2°C               |

### **Cox (Year 2)**

Cox apples were harvested on three occasions: 6, 13 and 20 September 2010 from the same orchard as the previous year and harvest maturity measurements, storage regimes and storage assessments were conducted as in year 1. Samples of apples were also inoculated with *Nectria* conidia as in year 1. Storage treatments 1, 2, 3, 6 and 7 (Table 1.1) used in year 1 were repeated in year 2.

### **Braeburn (Year 3)**

Braeburn apples from six orchards, comprising four Hilwell and two Lochbuie clones were picked during the week beginning 4 October. Storage samples were cooled for 48 hours, before a holding CA of 2% O<sub>2</sub> was established by respiration and maintained for 10 days. The final storage CA regime of 1.2% O<sub>2</sub> was then established through fruit respiration. Fruit was subject to periods of modulated temperature (Table 3.1), each lasting 70 days, of either a standard (1.5-2°C) or low temperature regime (0.5-1.0°C). Delayed ethylene scrubbing was applied using 5 kg bags of potassium permanganate coated clay beads into selected cabinets after the first 70 days of storage. Harvest maturity measurements and storage quality measurements were conducted as in previous years.

**Table 3.1.** Temperature regimes assessed during the Braeburn storage trials 2011-2012

| <b>Treatment</b> | <b>0 – 70 days</b> | <b>70 – 140 days</b> | <b>140 – 210 days</b> |
|------------------|--------------------|----------------------|-----------------------|
| 1                | 1.5-2°C            | 1.5-2°C              | 1.5-2°C               |
| 2                | 1.5-2°C            | 1.5-2°C              | 0.5-1°C               |
| 3                | 1.5-2°C            | 0.5-1°C              | 0.5-1°C               |
| 4                | 0.5-1°C            | 1.5-2°C              | 1.5-2°C               |
| 5                | 0.5-1°C            | 0.5-1°C              | 1.5-2°C               |
| 6                | 0.5-1°C            | 0.5-1°C              | 0.5-1°C               |
| 7*               | 1.5-2°C            | 1.5-2°C              | 1.5-2°C               |
| 8*               | 0.5-1°C            | 0.5-1°C              | 0.5-1°C               |

\*Delayed ethylene scrubbing after 70 days

## Results: Cox modulated temperature storage 2009-2011

### Cox (Year 1)

#### Harvest maturity measurements

In the 2009 season Cox was harvested within the correct harvest window (Table 1.2), firmness were high at 92 Newtons (9.2 kg), starch scores on the CTFL starch clearance patterns were 3.9, equivalent to just under 70% coverage and sugars were 12.1%. Fruit mineral analysis at harvest showed that calcium content was above the threshold of 5 mg 100g<sup>-1</sup> FW and suitable for long-term storage, the ratio of K/Ca was 30 (Table 1.3).

**Table 1.2.** Harvest maturity measurements

| Firmness    | Sugars (% Brix) | Starch (CTFL score) |
|-------------|-----------------|---------------------|
| 92.3 (3.74) | 12.10 (0.47)    | 3.90 (1.5)          |

Figures in brackets are LSD<sub>0.05</sub>

**Table 1.3.** Fruit mineral analysis at harvest

| N                    | P  | K   | Ca   | Mg  | Mn                 | B    | Fe   |
|----------------------|----|-----|------|-----|--------------------|------|------|
| mg/100g fresh weight |    |     |      |     | mg/kg fresh weight |      |      |
| 45                   | 16 | 175 | 5.81 | 6.7 | 5.2                | 3.28 | 4.40 |

#### Storage Trials - inspection 1: November 2009

The ex-store firmness of Cox dropped approximately 10 N in the first two months of storage (Table 1.4) in untreated fruit whilst the drop in firmness in SmartFresh™ treated fruit was approximately 5-7 N. SmartFresh™-treated fruit was generally firmer than untreated fruit by 2-6 N. The lower storage temperature reduced the rate of softening in non-treated fruit and the retention of background green colour (Colour a).

SmartFresh™ prevented loss of firmness during shelf-life (Table 1.5) however; the combination of SmartFresh™-treated fruit and storage at 1.5°C did not improve firmness retention. The firmness of untreated fruit dropped by approximately 20 N during shelf-life but fruits stored at 1.5°C were 5-6 Newtons (0.5-0.6 kg) firmer than those stored at 3.5°C. Background green colour (Colour a) dropped in all treatments

during shelf-life however the rate of de-greening was less apparent in SmartFresh™-treated fruit.

#### *Storage trials - Inspection 2: January 2010*

SmartFresh™-treated fruit remained firm with no change in ex-store firmness since the previous inspection (Table 1.6). Storage at lower temperatures (1.5 °C) for two or four months had a benefit on the firmness of untreated fruit (treatments 5 and 6) were 6-9 Newtons (0.6-0.9 kg) firmer than those that had been at 3.5°C (59.9-64.4 N) for the same period. No incremental benefit of firmness retention was achieved by combining SmartFresh™ and low-temperature storage fruit.

The rate of softening during shelf-life was reduced in Cox that had previously been stored at 1.5°C (Table 1.7). This difference was observed in SmartFresh™-treated and untreated fruit. However, untreated fruit softened (~30 N) significantly during shelf-life. Moreover, the soluble solid content (% Brix) of fruit during shelf-life was higher where fruit had been stored previously at 1.5°C and/or treated with SmartFresh™, suggesting that the rate of metabolism had been reduced. The retention of background green colour was only observed in SmartFresh™-treated fruit.

**Table 1.4.** Quality assessment of Cox apples after two months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at either 1.5 or 3.5°C (November-ex-store)

| Treatment                      | Firmness (N)*<br>SmartFresh™ |             | Brix (%)    |      | Colour a    |             | Colour b    |      | % Water core |     |
|--------------------------------|------------------------------|-------------|-------------|------|-------------|-------------|-------------|------|--------------|-----|
|                                | Yes                          | No          | Yes         | No   | Yes         | No          | Yes         | No   | Yes          | No  |
| 1 (3.5°C)                      | <b>86.7</b>                  | 80.1        | 14.0        | 13.9 | -5.0        | -5.9        | 42.7        | 42.5 | 5.0          | 0   |
| 2 (3.5°C)                      | <b>87.1</b>                  | 82.4        | 14.1        | 14.7 | -5.1        | -5.7        | 41.7        | 42.4 | 5.0          | 0   |
| 3 (3.5°C)                      | 83.8                         | 83.1        | 13.6        | 13.3 | -4.9        | -5.7        | 41.7        | 42.8 | 0            | 0   |
| 4 (3.5°C)                      | 81.7                         | 76.4        | <b>13.0</b> | 13.4 | -5.7        | -5.5        | 42.1        | 44.0 | 0            | 0   |
| 5 (1.5°C)                      | 82.7                         | 84.1        | 13.5        | 13.8 | -5.5        | -5.7        | 43.3        | 42.7 | 5.0          | 0   |
| 6 (1.5°C)                      | <b>86.7</b>                  | 77.5        | 13.5        | 13.3 | <b>-5.9</b> | -5.5        | 42.5        | 39.6 | 5.0          | 0   |
| 7 (1.5°C)                      | <b>86.3</b>                  | <b>84.8</b> | 13.6        | 13.4 | -5.3        | -6.1        | <b>40.3</b> | 40.9 | 0            | 5.0 |
| 8 (1.5°C)                      | 84.4                         | 81.5        | 13.9        | 13.4 | <b>-5.9</b> | <b>-6.7</b> | 40.5        | 42.0 | 0            | 0   |
| LSD <sub>0.05</sub><br>(16 df) | 4.48                         |             | 0.83        |      | 0.76        |             | 2.26        |      | 8.38         |     |

\*To convert Newtons to kg pressure divide by 9.8 and a loss of starch

**Table 1.5.** Shelf-life quality assessment of Cox apples after two months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at either 1.5 or 3.5°C followed by 7 days at 20°C (November-shelf life)

| Treatment                      | Firmness (N)<br>SmartFresh™ |             | Brix (%) |      | Colour a    |      | Colour b |      | % Water core |     |
|--------------------------------|-----------------------------|-------------|----------|------|-------------|------|----------|------|--------------|-----|
|                                | Yes                         | No          | Yes      | No   | Yes         | No   | Yes      | No   | Yes          | No  |
| 1 (3.5°C)                      | 85.5                        | 62.0        | 13.7     | 14.0 | -4.0        | -3.1 | 44.1     | 49.4 | 0            | 0   |
| 2 (3.5°C)                      | 86.4                        | 59.1        | 14.1     | 14.1 | -3.4        | -2.6 | 44.9     | 50.3 | 0            | 0   |
| 3 (3.5°C)                      | 85.9                        | 59.5        | 14.0     | 14.1 | -3.8        | -3.7 | 44.0     | 50.9 | 0            | 0   |
| 4 (3.5°C)                      | 84.8                        | 59.2        | 13.8     | 13.9 | -4.1        | -2.6 | 44.3     | 49.0 | 0            | 0   |
| 5 (1.5°C)                      | 84.0                        | <b>65.9</b> | 13.7     | 13.9 | <b>-5.5</b> | -3.4 | 43.6     | 48.7 | 0            | 0   |
| 6 (1.5°C)                      | 86.0                        | 64.2        | 13.8     | 13.9 | -4.4        | -3.3 | 44.2     | 48.0 | 0            | 0   |
| 7 (1.5°C)                      | 83.7                        | 65.0        | 13.7     | 13.7 | -4.4        | -2.9 | 41.9     | 50.1 | 0            | 0   |
| 8 (1.5°C)                      | 87.1                        | <b>66.6</b> | 13.7     | 14.4 | -5.1        | -2.7 | 45.0     | 48.4 | 0            | 5.0 |
| LSD <sub>0.05</sub><br>(16 df) | 3.82                        |             | 0.45     |      | 1.39        |      | 2.41     |      | 3.75         |     |

**Table 1.6.** Quality assessment of Cox apples after four months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at combinations of 1.5 and 3.5°C (January-ex-store)

| Treatment<br>SmartFresh™          | Firmness (N) |             | Brix (%) |      | Colour a |      | Colour b |      | % Bitter pit |     | % LTB |     | % Water core |    |
|-----------------------------------|--------------|-------------|----------|------|----------|------|----------|------|--------------|-----|-------|-----|--------------|----|
|                                   | Yes          | No          | Yes      | No   | Yes      | No   | Yes      | No   | Yes          | No  | Yes   | No  | Yes          | No |
| 1 (3.5/3.5°C)                     | 84.3         | 64.4        | 14.2     | 14.7 | -3.8     | -4.7 | 45.2     | 45.1 | 0            | 0   | 0     | 0   | 0            | 0  |
| 2 (3.5/3.5°C)                     | 81.4         | 59.9        | 14.0     | 15.0 | -3.7     | -4.7 | 46.6     | 45.6 | 0            | 0   | 0     | 0   | 0            | 0  |
| 3 (3.5/1.5°C)                     | 82.8         | 64.2        | 14.4     | 13.9 | -4.5     | -5.4 | 44.4     | 45.6 | 0            | 0   | 0     | 0   | 0            | 0  |
| 4 (3.5/1.5°C)                     | 83.6         | 61.0        | 13.8     | 14.4 | -4.5     | -4.6 | 44.8     | 43.2 | 0            | 0   | 0     | 0   | 0            | 0  |
| 5 (1.5/1.5°C)                     | 83.9         | <b>73.0</b> | 14.1     | 14.5 | -4.9     | -5.2 | 44.5     | 44.7 | 0            | 0   | 0     | 0   | 0            | 0  |
| 6 (1.5/1.5°C)                     | 87.6         | <b>70.5</b> | 14.9     | 14.2 | -4.3     | -5.7 | 44.4     | 45.8 | 0            | 0   | 0     | 5.0 | 5.0          | 0  |
| 7 (1.5/3.5°C)                     | 84.4         | <b>70.8</b> | 14.4     | 14.6 | -4.8     | -4.7 | 44.7     | 44.8 | 0            | 0   | 0     | 0   | 0            | 0  |
| 8 (1.5/3.5°C)                     | 83.9         | 65.7        | 14.0     | 13.8 | -4.6     | -5.4 | 44.6     | 44.7 | 0            | 5.0 | 0     | 0   | 0            | 0  |
| <i>LSD</i> <sub>0.05</sub> (16df) | 3.87         |             | 1.17     |      | 1.20     |      | 2.47     |      | 3.75         |     | 3.75  |     | 3.75         |    |

**Table 1.7.** Shelf-life quality assessment of Cox apples after four months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at combinations of 1.5 and 3.5°C followed by 7 days at 18°C (January-shelf life)

| Treatment<br>SmartFresh™          | Firmness (N) |             | Brix (%)    |             | Colour a    |      | Colour b |      | % Bitter pit |    | % LTB |    | % Water core |     |
|-----------------------------------|--------------|-------------|-------------|-------------|-------------|------|----------|------|--------------|----|-------|----|--------------|-----|
|                                   | Yes          | No          | Yes         | No          | Yes         | No   | Yes      | No   | Yes          | No | Yes   | No | Yes          | No  |
| 1 (3.5/3.5°C)                     | 76.2         | 48.4        | 14.1        | 13.1        | -2.5        | -1.5 | 48.8     | 52.2 | 0            | 0  | 0     | 0  | 0            | 0   |
| 2 (3.5/3.5°C)                     | 80.0         | 50.4        | 14.4        | <b>14.6</b> | -1.6        | -1.2 | 48.3     | 52.3 | 0            | 0  | 0     | 0  | 5.0          | 0   |
| 3 (3.5/1.5°C)                     | <b>86.1</b>  | 50.9        | 13.9        | 13.6        | -3.2        | -1.9 | 48.2     | 52.1 | 0            | 0  | 0     | 0  | 0            | 5.0 |
| 4 (3.5/1.5°C)                     | <b>83.3</b>  | <b>53.1</b> | 14.5        | 13.3        | -2.3        | -1.8 | 48.7     | 51.0 | 0            | 0  | 0     | 0  | 0            | 0   |
| 5 (1.5/1.5°C)                     | <b>82.8</b>  | <b>57.2</b> | 14.1        | <b>14.2</b> | -3.4        | -2.3 | 45.7     | 49.2 | 0            | 0  | 0     | 0  | 0            | 5.0 |
| 6 (1.5/1.5°C)                     | <b>87.8</b>  | <b>55.6</b> | <b>15.5</b> | <b>13.9</b> | <b>-4.1</b> | -2.1 | 46.9     | 50.3 | 0            | 0  | 5.0   | 0  | 0            | 0   |
| 7 (1.5/3.5°C)                     | <b>84.6</b>  | <b>53.1</b> | 14.5        | <b>14.1</b> | -2.8        | -1.6 | 47.2     | 51.2 | 0            | 0  | 0     | 0  | 0            | 0   |
| 8 (1.5/3.5°C)                     | <b>83.6</b>  | 52.9        | 14.2        | <b>13.9</b> | -3.0        | -2.5 | 47.7     | 51.3 | 0            | 0  | 0     | 0  | 0            | 0   |
| <i>LSD</i> <sub>0.05</sub> (16df) | 4.59         |             | 0.66        |             | 1.10        |      | 1.82     |      | 0            |    | 3.75  |    | 2.60         |     |

**Table 1.8.** Quality assessment of Cox apples after six months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at combinations of 1.5 and 3.5°C (March-ex-store)

| Treatment                  | Firmness (N) |             | Brix (%) |      | Colour a<br>SmartFresh™ |      | Colour b |      | % Rotting |     | % Core flush |     | % LTB       |             |
|----------------------------|--------------|-------------|----------|------|-------------------------|------|----------|------|-----------|-----|--------------|-----|-------------|-------------|
|                            | Yes          | No          | Yes      | No   | Yes                     | No   | Yes      | No   | Yes       | No  | Yes          | No  | Yes         | No          |
| 1 (3.5/3.5/3.5°C)          | 75.9         | 51.9        | 13.5     | 13.4 | -0.7                    | -2.2 | 45.4     | 47.2 | 18.2      | 0.0 | 0.0          | 0.0 | 0           | 0           |
| 2 (3.5/3.5/1.5°C)          | <b>82.4</b>  | 52.8        | 13.9     | 13.9 | 0.2                     | -3.7 | 45.7     | 46.7 | 10.6      | 0.0 | 0.0          | 0.0 | 5.0         | 0           |
| 3 (3.5/1.5/1.5°C)          | 79.9         | 55.1        | 14.0     | 13.8 | -2.4                    | -4.7 | 45.8     | 46.0 | 0.0       | 4.2 | 0.0          | 0.0 | 5.0         | 0           |
| 4 (3.5/1.5/3.5°C)          | 79.6         | 54.3        | 14.1     | 14.1 | -2.7                    | -4.1 | 46.6     | 47.0 | 0.0       | 9.1 | 0.0          | 0.0 | 0           | 0           |
| 5 (1.5/1.5/1.5°C)          | <b>81.7</b>  | <b>60.6</b> | 13.8     | 14.0 | -3.2                    | -4.8 | 43.8     | 45.6 | 0.0       | 4.6 | 0.0          | 0.0 | <b>46.2</b> | 14.5        |
| 6 (1.5/1.5/3.5°C)          | <b>81.8</b>  | <b>58.2</b> | 14.6     | 13.7 | -3.5                    | -4.2 | 47.0     | 46.0 | 0.0       | 4.2 | 0.0          | 0.0 | 16.6        | 0           |
| 7 (1.5/3.5/3.5°C)          | 78.7         | <b>56.9</b> | 14.1     | 14.1 | -3.6                    | -4.5 | 46.7     | 46.5 | 8.3       | 0.0 | 0.0          | 0.0 | 0           | 0           |
| 8 (1.5/3.5/1.5°C)          | 79.6         | <b>58.0</b> | 14.1     | 14.4 | -2.3                    | -3.8 | 46.6     | 46.4 | 0.0       | 0.0 | <b>4.2</b>   | 0.0 | <b>25.0</b> | <b>23.2</b> |
| LSD <sub>0.05</sub> (16df) | 4.88         |             | 0.91     |      | 1.51                    |      | 2.2      |      | 5.58      |     | 3.11         |     | 18.36       |             |

**Table 1.9.** Shelf-life quality assessment of Cox apples after six months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at combinations of 1.5 and 3.5°C followed by seven days at 18°C (March-shelf life)

| Treatment<br>SmartFresh™   | Firmness (N) |             | Brix (%) |      | Colour a |      | Colour b |      | % Rotting |    | % Core flush |    | % LTB       |      |
|----------------------------|--------------|-------------|----------|------|----------|------|----------|------|-----------|----|--------------|----|-------------|------|
|                            | Yes          | No          | Yes      | No   | Yes      | No   | Yes      | No   | Yes       | No | Yes          | No | Yes         | No   |
| 1 (3.5/3.5/3.5°C)          | 58.1         | 46.4        | 13.7     | 13.9 | 3.1      | 0.7  | 49.8     | 49.4 | 5.0       | 0  | 20.0         | 0  | 0           | 0    |
| 2 (3.5/3.5/1.5°C)          | <b>68.0</b>  | 46.6        | 13.8     | 13.7 | 1.5      | 1.3  | 48.1     | 50.5 | 15.0      | 0  | 47.8         | 0  | 15.6        | 0    |
| 3 (3.5/1.5/1.5°C)          | <b>78.6</b>  | 46.8        | 14.1     | 13.5 | -0.6     | -0.2 | 48.9     | 50.2 | 5.5       | 0  | 0            | 0  | 22.2        | 0    |
| 4 (3.5/1.5/3.5°C)          | <b>67.4</b>  | 48.4        | 14.3     | 13.5 | 1.9      | 0.9  | 49.8     | 49.2 | 5.5       | 0  | 15.0         | 0  | 37.2        | 0    |
| 5 (1.5/1.5/1.5°C)          | <b>82.9</b>  | <b>51.8</b> | 14.0     | 13.7 | -1.8     | 0.4  | 47.5     | 49.2 | 0         | 0  | 0            | 0  | <b>60.0</b> | 30.0 |
| 6 (1.5/1.5/3.5°C)          | <b>73.8</b>  | <b>51.8</b> | 14.0     | 14.3 | -0.8     | 0.1  | 49.6     | 48.6 | 0         | 0  | 10.0         | 0  | 20.0        | 0    |
| 7 (1.5/3.5/3.5°C)          | <b>65.2</b>  | <b>52.2</b> | 14.2     | 14.7 | 1.6      | 0.0  | 49.5     | 49.0 | 10.0      | 0  | 21.1         | 0  | 5.6         | 0    |
| 8 (1.5/3.5/1.5°C)          | <b>75.2</b>  | 49.9        | 13.9     | 13.9 | 0.2      | 0.4  | 47.9     | 49.9 | 0         | 0  | 15.0         | 0  | 25.0        | 0    |
| LSD <sub>0.05</sub> (16df) | 4.71         |             | 0.83     |      | 1.98     |      | 2.24     |      | 15.21     |    | 20.0         |    | 28.25       |      |

**Table 1.10.** The effect of SmartFresh™ on the rate of respiration rates (ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>) of Cox's apples stored under modulated temperature regimes

| Treatment                  | November SmartFresh™ |             | January     |             | March       |      |
|----------------------------|----------------------|-------------|-------------|-------------|-------------|------|
|                            | Yes                  | No          | Yes         | No          | Yes         | No   |
| 1 (3.5/3.5/3.5°C)          | 1.54                 | 1.64        | 1.54        | 1.22        | 1.20        | 1.03 |
| 2 (3.5/3.5/1.5°C)          | <b>1.39</b>          | <b>1.28</b> | 1.55        | 1.37        | 1.25        | 0.92 |
| 3 (3.5/1.5/1.5°C)          | <b>1.32</b>          | 1.57        | <b>0.98</b> | 1.17        | 1.14        | 1.16 |
| 4 (3.5/1.5/3.5°C)          | <b>1.29</b>          | 1.54        | <b>1.07</b> | 1.18        | <b>1.46</b> | 1.12 |
| 5 (1.5/1.5/1.5°C)          | <b>1.19</b>          | <b>1.25</b> | <b>1.10</b> | 1.21        | 1.19        | 1.14 |
| 6 (1.5/1.5/3.5°C)          | <b>1.17</b>          | 1.51        | <b>1.37</b> | 1.33        | <b>1.36</b> | 1.07 |
| 7 (1.5/3.5/3.5°C)          | <b>1.38</b>          | 1.56        | 1.54        | <b>1.56</b> | <b>1.34</b> | 1.11 |
| 8 (1.5/3.5/1.5°C)          | <b>1.35</b>          | <b>1.42</b> | 1.57        | <b>1.56</b> | <b>1.34</b> | 1.07 |
| LSD <sub>0.05</sub> (16df) | 0.2                  |             | 0.16        |             | 0.16        |      |

Values in columns highlighted in bold are significantly different ( $p < 0.05$ ) from the untreated control (treatment 1).

**Table 1.11.** The incidence of *Nectria* lesions on SmartFresh™ treated Cox's Orange Pippin stored under modulated temperature regimes

| Treatment                  | SmartFresh™ |             |
|----------------------------|-------------|-------------|
|                            | Yes         | No          |
| 1 (3.5/3.5/3.5°C)          | 30.0        | 30.0        |
| 2 (3.5/3.5/1.5°C)          | 17.5        | <b>65.0</b> |
| 3 (3.5/1.5/1.5°C)          | <b>13.8</b> | <b>13.8</b> |
| 4 (3.5/1.5/3.5°C)          | 21.2        | 41.2        |
| 5 (1.5/1.5/1.5°C)          | <b>10.0</b> | <b>3.8</b>  |
| 6 (1.5/1.5/3.5°C)          | <b>11.2</b> | 33.8        |
| 7 (1.5/3.5/3.5°C)          | 17.5        | 25.0        |
| 8 (1.5/3.5/1.5°C)          | <b>12.5</b> | <b>78.8</b> |
| LSD <sub>0.05</sub> (16df) | 14.51       |             |

Values in columns highlighted in bold are significantly different ( $p < 0.05$ ) from the untreated control (treatment 1).

### *Storage trials - Inspection 3: March 2010*

Where Cox had been stored at initially at 1.5°C and then was stored for four out of the six month storage period at 1.5°C, a 4-6 N (0.4-0.6 kg) increase in firmness was recorded with fruit firmness ranging from 57-60 N (5.7-6 kg), however, Cox firmness was just below the commercial threshold (65 N) of acceptability (Table 1.8). This improvement in firmness was also seen with SmartFresh™-treated Cox apples, where fruit firmness over a six month storage period and were 20-25 N (2-2.5 kg) firmer than untreated fruit.

The incidence of LTB first appeared in the March inspection: Cox stored at 1.5°C for the whole of the season was worst affected (46.2%), while those that started at 1.5°C and then received a second period at 1.5°C also suffered from LTB. A small amount of core flush was also recorded in SmartFresh™-treated Cox stored 1.5/3.5/1.5°C (treatment 8). Rotting in SmartFresh™-treated fruit was highest where Cox had been stored at 3.5°C for the first four-six months.

SmartFresh™-treated Cox stored at 1.5°C for the whole six-month period maintained firmness and was 24.8 Newtons (2.5 kg) firmer than fruit stored at 3.0-3.5°C for the entire six months (Table 1.9). Untreated fruit were significantly softer than SmartFresh™-treated fruit and although treatments (5, 6 and 7) improved firmness retention compared to the control, firmness was below the threshold of marketability.

Low temperature breakdown was more evident after shelf-life and fruit stored at 1.5°C for the whole period had 60% LTB affected fruit; fruits stored at 3.5°C for the whole period showed signs of senescent breakdown (20%) which was not evident in other treatments. Late season core-flush was most evident in Cox stored for the first four months at 3.5°C but also in Cox stored for 3.5°C for the whole period or where two of the storage periods were at 3.5°C.

### *Storage trial - Fruit respiration*

A general decline in fruit respiration during storage was seen in untreated fruit (Table 1.10), In November respiration range from 1.3-1.6 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> and by the final inspection respiration rates were between 0.9-1.2 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>. Initially SmartFresh™ had a suppressive effect on respiration, but with time this effect was less apparent. There was no significant effect of low-temperature storage on fruit respiration and the incidence of LTB was not correlated with a rise in respiration

### Storage trial - *Nectria* rots

SmartFresh™ generally reduced the incidence of rotting in inoculated fruit compared to untreated (Table 1.11). Storage at lower temperature combined with SmartFresh™ treatment reduced the incidence of rotting; those that had been stored at 1.5°C for the whole period had the lowest incidence of rotting. Without SmartFresh™ there was a high degree of variability between treatments, although continuous storage at 1.5°C lowered the incidence of rotting. However, in treatments that combined periods of storage at 3.5°C and 1.5°C rot control was less successful. Although low-temperature storage may have some merit in reducing the onset of late-season cryptic infections such as *Nectria*, the increased risk of LTB would prevent this control strategy from being adopted.

### Cox (Year 2)

#### Harvest maturity measurements

Firmness of fruit was slightly lower than the 8.5 kg pressure desired for long-term storage (Table 2.2). Interestingly, there was little increase in the internal ethylene concentration (IEC) between pick 1 and 2, despite a loss of starch and harvest firmness being 7 N lower in the second pick. By the third pick fruit firmness dropped only 5.6 N between the three picks, despite the internal ethylene doubling between picks 2 and 3.

**Table 2.2.** Harvest maturity measurements

| Pick                             | Firmness (N) | I.E.C ppb    | Sugars (% Brix) | Starch (CTFL score) | Colour a    | Colour b    |
|----------------------------------|--------------|--------------|-----------------|---------------------|-------------|-------------|
| 1 (7/9/10)                       | 77.7         | 59.5         | 12.7            | 4.8                 | -7.8        | 45.0        |
| 2 (14/9/10)                      | 71.4         | 52.9         | 12.0            | 6.6                 | -6.5        | 42.0        |
| 3 (21/9/10)                      | 72.1         | 137.1        | 13.6            | 5.8                 | -5.6        | 43.2        |
| <b>LSD<sub>0.05</sub> (3 df)</b> | <b>8.82</b>  | <b>32.13</b> | <b>0.78</b>     | <b>1.05</b>         | <b>1.57</b> | <b>2.62</b> |

Nutrition analysis of Cox at harvest (Table 2.3) revealed that fruit calcium content was above the minimum of 5 mg per 100g at harvest and that potassium content was below 150 mg/100g ensuring that the calcium: potassium ratio was maintained below 30.

**Table 2.3.** Fruit mineral analysis at harvest

| N                    | P    | K   | Ca  | Mg  | Mn                 | B    | Fe   | Cu   |
|----------------------|------|-----|-----|-----|--------------------|------|------|------|
| mg/100g fresh weight |      |     |     |     | mg/kg fresh weight |      |      |      |
| 76                   | 12.4 | 137 | 5.8 | 6.3 | 0.52               | 2.53 | 6.35 | 0.40 |

Cox was inspected ex-store in November, January and March, with additional assessments being made after one week's shelf-life at 18°C following each inspection

#### *Storage trial - November 2010 inspection (60 days)*

Harvest date of fruit had a large influence on the storage quality of Cox apples and retention of fruit quality declined with each week of delay in picking date. Picking fruit beyond the optimum picking date (P1) led to an accelerated rate of softening that wasn't reduced by storage at lower temperatures (Table 2.4). This confirmed the need to pick fruit within a limited harvest window.

Storing SmartFresh™-treated fruit from pick 1 at 1.5°C afforded a 3 N improvement in firmness (79.7 N) compared to storage at 3.5°C (76.8 N). Overall, SmartFresh™-treated fruit were firmer than untreated fruit but a general decline in firmness was observed with later harvest dates (Table 2.4).

SmartFresh™-treated Cox from all three picks did not soften during a week's shelf-life at 18°C. Moreover, no effect of storage temperature on the ex-shelf life firmness was observed (Table 2.5). Untreated fruit softened extensively during shelf-life (Table 2.5) to below the commercially acceptable threshold of 60 N, and an increased rate of fruit softening was observed in later harvested fruit.

#### *Storage trial - January 2010 inspection (120 days)*

After four months storage, untreated fruit had softened to below the threshold of commercial acceptability (65 N). The 2011-2012 growing season was particularly challenging and fruit softened excessively during storage, despite early harvested fruit being picked within the optimum harvest window. Storing Cox at 1.5°C for two or four months failed to control the rate of softening

SmartFresh™ prevented loss of fruit firmness over all the picking dates and no additional benefit for ex-store or ex-shelf firmness was achieved by storing Cox at 1.5°C (Table 2.6). After a week's shelf-life all non-SmartFresh™-treated Cox were softer than the commercially acceptable threshold of 60 N (Table 2.7) while SmartFresh™-treated fruit firmness remained between 61-73 N after shelf-life. No benefit of low-temperature storage was accrued by storing fruit at 1.5°C prior to shelf-life.

### *Storage trial - March 2011 inspection (180 days)*

Ex-store firmness of fruit from the final inspection in March was only marginally less than the previous inspection in January. Fruit firmness of untreated fruit from the first two picks remained above the commercial threshold of 65 N after six months storage (69.7 N and 67.6 N, respectively) while late-picked fruit (pick 3) averaged 53.8 N and were considered soft and mealy. This further underlines the need to pick fruit within the optimum harvest window to ensure long-term storage quality.

Low temperature storage failed to impact on the rate of softening in untreated Cox (Table 2.8). Incorporating periods of low-temperature into the storage regime failed to control the rate of softening in Cox apples from different pick dates (Table 2.8). More importantly where Cox had been subject to at least four months of storage at 1.5°C fruits underwent excessive softening due increased physiological stress.

SmartFresh™ treatments maintained ex-store firmness retention and fruit from picks 1-3 averaged 75.7 N, 74.5 N and 70.3 N respectively. The softening patterns during shelf-life did not follow the expected pattern. SmartFresh™-treated Cox from pick 1 fruit softened considerably during shelf-life to below the 60 N threshold while SmartFresh™-treated Cox from pick 2 and 3 fruit remained above 60 N (Table 2.9). Non-SmartFresh™-treated fruit from all storage treatments softened below the 60 N threshold after a week's shelf-life at 18°C (Table 2.9).

### *Storage trial – Respiration*

In general, an increase in fruit respiration was recorded where Cox consignments were subject to 60 days at 1.5°C (1.4-1.6 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>) compared to fruit stored at 3.5°C (0.9-1.0 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>). The rise in respiration in lower storage temperatures was attributable to a stress related rise in respiration rates, and this was suppressed by the application of SmartFresh™ (Table 2.10).

**Table 2.4.** Quality assessment of Cox apples after two months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at either 1.5 or 3.5°C (November-ex-store)

| Treatment                                   | Firmness (N)*<br>Pick 1 |             | Firmness (N)<br>Pick 2<br>SmartFresh™ |             | Firmness (N)<br>Pick 3 |              |
|---|-------------------------|-------------|---------------------------------------|-------------|------------------------|--------------|
|   | Yes                     | No          | Yes                                   | No          | Yes                    | No           |
| 1 (3.5°C)                                   | 76.10                   | 77.30       | 71.20                                 | 71.15       | 66.10                  | 65.0         |
| 2 (3.5°C)                                   | 76.45 (76.8)            | 75.65(76.5) | 71.85(72.3)                           | 68.85(70.0) | 69.35(68.3)            | 63.80 (64.4) |
| 3 (3.5°C)                                   | 78.00                   | 76.50       | 73.95                                 | 69.95       | 69.40                  | 64.55        |
| 6 (1.5°C)                                   | 79.80 (79.7)            | 78.55(77.2) | 74.60(73.9)                           | 72.30(71.7) | 69.95 (70.3)           | 67.70 (67.1) |
| 7 (1.5°C)                                   | 79.55                   | 75.95       | 73.25                                 | 71.10       | 70.70                  | 66.50        |
| <b>LSD<sub>0.05</sub></b><br><b>(30 df)</b> | <b>3.159</b>            |             |                                       |             |                        |              |

Figures in parenthesis are mean values of T1-3 (3.5°C) and T6-7 (1.5°C). To convert N to kg pressure divide by 9.8 (~10).

**Table 2.5.** Shelf-life quality assessment of Cox apples after two months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at either 1.5 or 3.5°C followed by seven days at 18°C (November-shelf life)

| Treatment                                   | Firmness (N)<br>Pick 1 |              | Firmness (N)<br>Pick 2<br>SmartFresh™ |              | Firmness (N)<br>Pick 3 |              |
|---|------------------------|--------------|---------------------------------------|--------------|------------------------|--------------|
|   | Yes                    | No           | Yes                                   | No           | Yes                    | No           |
| 1 (3.5°C)                                   | 75.25                  | 58.40        | 72.35                                 | 52.10        | 70.25                  | 49.20        |
| 2 (3.5°C)                                   | 76.15 (75.3)           | 56.95 (57.1) | 73.15 (73.5)                          | 52.40 (56.6) | 72.50 (72.1)           | 49.70(50.0)  |
| 3 (3.5°C)                                   | 74.5                   | 56.95        | 75.05                                 | 56.40        | 73.55                  | 50.95        |
| 6 (1.5°C)                                   | 79.75 (78.8)           | 57.50 (56.6) | 73.35 (73.0)                          | 53.85(54.2)  | 71.50(70.4)            | 51.45 (51.3) |
| 7 (1.5°C)                                   | 77.9                   | 55.65        | 72.60                                 | 54.50        | 69.30                  | 51.10        |
| <b>LSD<sub>0.05</sub></b><br><b>(30 df)</b> | <b>3.656</b>           |              |                                       |              |                        |              |

Figures in parenthesis are mean values of T1-3 (3.5°C) and T6-7 (1.5°C)

**Table 2.6.** Quality assessment of Cox apples after four months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at either 1.5 or 3.5°C (January-ex-store)

| Treatment                             | Firmness (N)<br>Pick 1 |       | Firmness (N)<br>Pick 2 |       | Firmness (N)<br>Pick 3 |       |
|---------------------------------------|------------------------|-------|------------------------|-------|------------------------|-------|
|                                       | Yes                    | No    | Yes                    | No    | Yes                    | No    |
| 1 (3.5°C)                             | 77.50                  | 71.20 | 71.95                  | 66.30 | 72.05                  | 58.15 |
| 2 (3.5°C)                             | 78.70                  | 71.25 | 70.10                  | 65.10 | 70.00                  | 59.65 |
| 3 (3.5°C)                             | 73.75                  | 58.10 | 72.20                  | 55.55 | 69.15                  | 48.20 |
| 6 (1.5°C)                             | 77.20                  | 60.40 | 72.45                  | 56.40 | 71.95                  | 55.45 |
| 7 (1.5°C)                             | 76.35                  | 70.80 | 71.75                  | 64.30 | 71.80                  | 60.00 |
| <b>LSD<sub>0.05</sub><br/>(30 df)</b> | <b>3.883</b>           |       |                        |       |                        |       |

**Table 2.7.** Shelf-life quality assessment of Cox apples after four months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at either 1.5 or 3.5°C followed by seven days at 18°C (January-shelf life)

| Treatment                             | Firmness (N)<br>Pick 1 |       | Firmness (N)<br>Pick 2 |       | Firmness (N)<br>Pick 3 |       |
|---------------------------------------|------------------------|-------|------------------------|-------|------------------------|-------|
|                                       | Yes                    | No    | Yes                    | No    | Yes                    | No    |
| 1 (3.5°C)                             | 65.75                  | 52.75 | 71.60                  | 49.55 | 70.80                  | 48.05 |
| 2 (3.5°C)                             | 61.20                  | 51.00 | 70.60                  | 51.25 | 71.80                  | 47.30 |
| 3 (3.5°C)                             | 62.00                  | 46.65 | 71.70                  | 43.45 | 68.65                  | 40.95 |
| 6 (1.5°C)                             | 70.50                  | 49.80 | 71.90                  | 47.25 | 70.30                  | 43.25 |
| 7 (1.5°C)                             | 63.60                  | 53.55 | 72.85                  | 49.20 | 69.75                  | 46.75 |
| <b>LSD<sub>0.05</sub><br/>(30 df)</b> | <b>3.421</b>           |       |                        |       |                        |       |

**Table 2.8.** Quality assessment of Cox apples after six months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at either 1.5 or 3.5°C (March-ex-store)

| Treatment                             | Firmness (N)<br>Pick 1 |       | Firmness (N)<br>Pick 2 |       | Firmness (N)<br>Pick 3 |       |
|---------------------------------------|------------------------|-------|------------------------|-------|------------------------|-------|
|                                       | Yes                    | No    | Yes                    | No    | Yes                    | No    |
| 1 (3.5°C)                             | 75.70                  | 69.75 | 74.5                   | 67.65 | 70.35                  | 53.85 |
| 2 (3.5°C)                             | 75.45                  | 64.05 | 70.35                  | 60.10 | 69.70                  | 52.15 |
| 3 (3.5°C)                             | 66.90                  | 52.00 | 69.55                  | 49.10 | 67.55                  | 44.70 |
| 6 (1.5°C)                             | 74.90                  | 57.55 | 70.80                  | 52.45 | 69.80                  | 48.55 |
| 7 (1.5°C)                             | 78.45                  | 69.45 | 71.65                  | 64.55 | 70.55                  | 57.45 |
| <b>LSD<sub>0.05</sub><br/>(30 df)</b> | <b>2.971</b>           |       |                        |       |                        |       |

**Table 2.9.** Shelf-life quality assessment of Cox apples after six months storage (1.25% O<sub>2</sub>, <1% CO<sub>2</sub>) at either 1.5 or 3.5°C followed by seven days at 18°C (March-shelf life)

| Treatment                             | Firmness (N)<br>Pick 1 |       | Firmness (N)<br>Pick 2 |       | Firmness (N)<br>Pick 3 |       |
|---------------------------------------|------------------------|-------|------------------------|-------|------------------------|-------|
|                                       | Yes                    | No    | Yes                    | No    | Yes                    | No    |
| 1 (3.5°C)                             | 53.75                  | 51.95 | 65.75                  | 50.35 | 67.80                  | 45.60 |
| 2 (3.5°C)                             | 54.80                  | 47.65 | 69.70                  | 47.35 | 67.95                  | 44.10 |
| 3 (3.5°C)                             | 50.10                  | 43.05 | 71.55                  | 39.75 | 67.35                  | 37.40 |
| 6 (1.5°C)                             | 52.65                  | 42.50 | 69.90                  | 40.35 | 68.85                  | 37.65 |
| 7 (1.5°C)                             | 53.15                  | 49.70 | 69.70                  | 46.65 | 68.50                  | 46.00 |
| <b>LSD<sub>0.05</sub><br/>(30 df)</b> | <b>4.260</b>           |       |                        |       |                        |       |

**Table 2.10.** The effect of SmartFresh™ on the rate of respiration rates (ml CO<sub>2</sub> kg<sup>-1</sup> hr<sup>-1</sup>) of Cox's Orange Pippin stored under modulated temperature regimes

| Treatment           | 60 days |      | 120 days<br>SmartFresh™ |      | 180 days |      |
|---------------------|---------|------|-------------------------|------|----------|------|
|                     | Yes     | No   | Yes                     | No   | Yes      | No   |
| 1 (3.5/3.5/3.5°C)   | 0.9     | 0.88 | 1.21                    | 1.47 | 0.96     | 0.29 |
| 2 (3.5/3.5/1.5°C)   | 0.66    | 0.96 | 1.20                    | 1.19 | 0.64     | 0.70 |
| 3 (3.5/1.5/1.5°C)   | 0.83    | 0.97 | 1.46                    | 1.91 | 0.79     | 1.10 |
| 6 (1.5//1.5//3.5°C) | 0.85    | 1.63 | 1.49                    | 2.29 | 1.04     | 1.47 |
| 7 (1.5/3.5/3.5°C)   | 0.81    | 1.41 | 1.21                    | 1.39 | 0.55     | 0.76 |
| LSD <sub>0.05</sub> | 0.402   |      |                         |      |          |      |

**Table 2.11.** The incidence of *Nectria* lesions on SmartFresh™ treated Cox's Orange Pippin stored under modulated temperature regimes

| Treatment                         | Pick 1       |     | Pick 2<br>SmartFresh™ |     | Pick 3 |    |
|-----------------------------------|--------------|-----|-----------------------|-----|--------|----|
|                                   | Yes          | No  | Yes                   | No  | Yes    | No |
| 1 (3.5/3.5/3.5°C)                 | 81           | 100 | 99                    | 100 | 87     | 93 |
| 2 (3.5/3.5/1.5°C)                 | 87           | 99  | 93                    | 100 | 80     | 76 |
| 3 (3.5/1.5/1.5°C)                 | 69           | 96  | 84                    | 91  | 67     | 80 |
| 6 (1.5//1.5//3.5°C)               | 70           | 92  | 85                    | 86  | 51     | 69 |
| 7 (1.5/3.5/3.5°C)                 | 85           | 98  | 84                    | 96  | 72     | 77 |
| <b>LSD<sub>0.05</sub> (30 df)</b> | <b>13.08</b> |     |                       |     |        |    |

Respiration rates at 120 days were generally higher than after 60 days (Table 2.10). Averaged over three picks the respiration rate of untreated fruit stored previously at 3.5°C was 1.2 to 1.5 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> and increased to 1.9-2.3 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> where fruit had been stored at 1.5°C. While SmartFresh™ treatments suppressed the rise in stress respiration, fruit stored at 3.5°C were between 1.20-1.21 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> but this increased to between 1.46 and 1.49 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> where fruit was stored at 1.5°C. This suggested that low-temperature storage had induced physiological stress in fruit and these treatments went on to induce excessive fruit softening.

After 180 days storage respiration rates had declined. However, a similar trend in respiration rates was seen between fruits stored at 1.5 and 3.5°C. Treatments where fruit had either been kept at 3.5°C or limited to two months at 1.5°C had respiration rates ranging from 0.29-0.76 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>, while those stored under extended periods (four months) at 1.5°C had elevated respiration rates between 1.10 and 1.47 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>. The range of respiration rates in SmartFresh™-treated apples was generally lower and stress respiration was suppressed. Respiration rates for fruit kept at 3.5°C, or with limited low-temperature storage, ranged between 0.6 to 1.0 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> while fruit stored for four months at 1.5°C had respiration rates of between 0.8 and 1.0 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>.

#### *Storage trial - Physiological disorders - core flush and low temperature breakdown (LTB)*

In the second year of the trial the risk prediction for LTB and core flush development in Cox was low and no incidence of core flush was observed during the six month storage period. The first incidence of LTB was seen in shelf-life samples of Cox stored for 120 days at 1.5°C (T6), where pick 1 fruit had 10% LTB and it was 5% in pick 3 fruit (data not presented).

After 180 days storage, ex-store inspection found small numbers of fruit with LTB where low temperatures had been incorporated into the storage regime. The worst regime for inducing LTB was treatment 3 (60 days at 3.5°C and 120 days at 1.5°C), where SmartFresh™-treated fruit from pick 2 had 15% LTB, rising to 35% in pick 3. treatment 6 also induced LTB - pick 1 SmartFresh™-treated fruit developed 15% LTB increasing to 50% in pick 2, while LTB was absent in pick 3.

### *Storage trial - Incidence of rotting*

Reducing storage temperatures to 1.5°C for four months of the six month storage period led to a reduction in *Nectria* rots (Table 2.11). Applying low-temperature earlier on in the storage period had a greater benefit in reducing *Nectria* than reducing temperatures later in the storage term. However, this treatment had a deleterious effect on fruit softening and so cannot be considered an alternative strategy in its current form

### **Conclusions- Cox modulated temperature storage 2009-2011**

- Incorporating periods of CA storage at 1.5°C for between two and four months reduced the rate of softening and the incidence of *Nectria* rotting. However, under low temperature storage fruit underwent an increase in stress respiration, which in the long term led to a higher incidence of LTB (30%) in Cox fruits. This precludes the use of this treatment for long-term storage of Cox
- Stress-induced respiration in Cox stored at 1.5°C was suppressed by the application of SmartFresh™. Shorter periods of storage at 1.5°C, with the remaining storage at 3.5°C, prevented the occurrence of LTB
- Cox receiving periods of low temperature (1.5°C) storage at the beginning of the season were slightly firmer than where low temperatures were applied later in the storage period. However, fruits were more predisposed to LTB and core flush when subjected to low temperatures early on in the storage season.
- SmartFresh™ maintained firmness ex-store and throughout the shelf life period, whilst reducing the incidence of rotting
- SmartFresh™ was most effective in minimizing softening and disease occurrence when combined with low temperature storage. However, continuous storage at 1.5°C combined with SmartFresh™ treatments led to a high incidence of LTB (60%)
- No additional benefit of intermittent warming or cooling was observed compared to other treatments. Therefore it has been decided to discontinued these treatments along with continuous low temperature storage.

## Results- Braeburn modulated temperature storage 2011-2012

### *Braeburn (Year 3)*

#### *Harvest maturity measurements*

Picking fruit at optimum maturity for long-term storage is a major factor in reducing the incidence of core flush and Braeburn browning disorder (BBD). Delaying harvest until fruit reaches 50% red colour can lead to elevated internal ethylene concentrations. Above a threshold of 100 ppb ethylene, many ripening related processes are hard to control under CA storage. A significant proportion of fruit in the trial had already exceeded 100 ppb ethylene. Starch clearing patterns, although generally indicative of harvest maturity, were not as sensitive at discriminating fruit maturity when compared to fruit internal ethylene status (IEC) (Table 3.2). Moreover, % Brix was related more to dry matter content of fruit at harvest (data not presented) than increasing harvest maturity.

The orchard where a high incidence of core-flush was recorded (orchard N) was the most-mature orchard at harvest with IEC at harvest of 538 ppb and a respiration rate of 7.4 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> compared to the other orchards where IEC ranged from 76-130 ppb and respiration at harvest 5.3-6.3 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup>. Mineral nutrition in all orchards was good, with calcium content above the threshold of 5 mg 100g<sup>-1</sup> and calcium/potassium ratios below 30 making all fruit capable of long-term storage (April) based on mineral composition. The K/Ca ratio should not exceed 30, while Ca concentrations should be in excess of 5 mg/100g fresh tissue for long-term storage.

#### *Storage trial - Inspection 1 (70 days)*

Firmness of fruit remained high in all orchards in December (Table 3.3) and changed little after a week's shelf-life at 18°C (Table 3.3). Storing fruit at 0.5-1.0°C showed no significant benefit over standard temperature (1.5-2.0°C). Similarly, sugars remained stable, with little overall changes and orchard B fruit had significantly higher sugars (Table 3.3). Moreover, no significant benefit to background green colour retention was accrued by storing fruit at lower storage temperatures during the first 70 days of storage (Table 3.4). Fruit quality remained robust after a week's shelf-life and no significant deterioration in quality was observed.

**Table 3.2.** The maturity of Braeburn clones at harvest

| <b>Orchard<br/>(clone)</b> | <b>Fruit<br/>size<br/>(mm)</b> | <b>Int.<br/>Ethylene<br/>(ppb)</b> | <b>Resp.<br/>Rate<br/>mICO<sub>2</sub>/kg</b> | <b>CTIFL<br/>Starch<br/>cover</b> | <b>%<br/>Brix</b> | <b>% Red<br/>Colour</b> | <b>Firmness<br/>kg</b> | <b>% Dry<br/>matter</b> | <b>Ca<br/>mg/100g</b> | <b>K/Ca*</b> |
|----------------------------|--------------------------------|------------------------------------|---|-----------------------------------|-------------------|-------------------------|------------------------|-------------------------|-----------------------|--------------|
| B (H)                      | 70.3                           | 114.9                              | 5.62  | 3                                 | 13.4              | 65                      | 10.5                   | 17.2                    | 6.60                  | 18.7         |
| E (H)                      | 75.6                           | 146                                | 6.02  | 4                                 | 11.2              | 65                      | 10.1                   | 14.5                    | 6.50                  | 18.6         |
| J ( L)                     | 75.9                           | 76.5                               | 6.19  | 4                                 | 11.3              | 78                      | 10.2                   | 15.2                    | 8.77                  | 11.0         |
| Mi (H)                     | 72.1                           | 96.5                               | 5.74  | 4                                 | 12.0              | 60                      | 9.5                    | 16.0                    | 7.47                  | 9.2          |
| My (H)                     | 72.7                           | 128.8                              | 5.31  | 5                                 | 12.0              | 71                      | 9.1                    | 15.3                    | 7.15                  | 13.2         |
| N (L)                      | 78.3                           | 538.5                              | 7.38  | 5                                 | 11.6              | 67                      | 10.4                   | 15.7                    | 7.66                  | 16.5         |

H = Hilwell, L= Lochbuie

### *Storage trial - Inspection 2 (140 days)*

Braeburn stored for 140 days at 0.5-1.0°C were marginally firmer than those stored at 1.5-2.0°C (Table 3.5), however, the response was variable amongst orchards and replicates. Nonetheless, firmness remained good in all orchards (8.6-9.6 kg), after a week's shelf-life treatment differences were absent but overall firmness of fruit was high (8.2-9.4 kg) in fruit stored at 1.5-2.0°C and 8.2-9.2 kg in fruit stored at 0.5-1.0°C (Table 3.6). There was no effect of storage temperature or ethylene scrubbing on sugar content (Tables 3.7, 3.8). However, with respect to retention of green background colour, delayed ethylene scrubbing maintained green background in fruit subject to shelf-life from orchards that were more mature at harvest (Tables 3.9, 3.10). The incidence of rotting was highest in Orchard N: the most mature fruit at harvest. The incidence of rotting (brown rot) was restricted to fruit from Orchard N which was over-mature at harvest (Table 3.11) and during shelf-life an increase in the number of fruit affected was recorded (Table 3.12). Apart from increasing the propensity of fruit to develop rots, fruits that are more mature at harvest are prone to development of core flush (Table 3.13). During shelf-life the incidence of core flush increased in these orchard consignments (Table 3.14).

### *Storage trial - Inspection 3 (210 days)*

At the final inspection, fruit from all orchard consignment's remained firm (80-90 N). In some cases fruit were firmer where delayed ethylene scrubbing was applied (Table 3.15), although this was dependant on orchard consignment. Storing fruit at lower temperature for the full 210 days of storage delayed the loss of firmness in fruit from some modulating temperature between 1.5-2.0°C and 0.5-1.0°C was not consistent in reducing loss of firmness. After seven days shelf-life fruit remained firm and orchard to orchard variation in response to treatment was observed (Table 3.16). Delayed ethylene scrubbing or incorporating periods of lower temperature reduced softening. However, firmness in all treatments was above the commercial threshold of acceptability.

The sugar content of fruit was not affected by storage treatments (Table 3.17) and changed little after additional shelf-life testing (Table 3.18). Background green colour of Braeburn varied between orchard consignments, with fruit that was over-mature at harvest being the least green coming out of store (Table 3.19). This effect was acerbated following an additional seven days of shelf-life (Table 3.20). The incidence of rotting was not affected by storage regime - the highest incidence was seen where

fruit was over mature at harvest (Tables 3.21, 3.22). Similarly, the incidence of late-season core flush was most evident in Braeburn from orchard N, where fruit was more mature at harvest (Table 3.23). The amount of core flush was variable between treatments and increased significantly during shelf-life (Table 3.24).

The incidence of senescent breakdown (Table 3.25) was again related to fruit with greater maturity at harvest (Orchard N) and was higher in fruit exposed to low temperature storage (0.5-1.0°C). Interestingly, in orchard consignments where respiration rates of fruit kept at 18°C was above 6.0 mls CO<sub>2</sub>/kg/h core flush was more prevalent. In some orchards the incidence of core flush was reduced where delayed scrubbing had been applied. Moreover, Braeburn consignments that were prone to internal flesh breakdown were lower in boron, being below the threshold (2.5 mg kg<sup>-1</sup>). Low boron content can increase the propensity to browning disorders in pears.

### **Conclusions- Braeburn modulated temperature storage 2011-2012**

- The harvest maturity of Braeburn entering store had a significant effect on the propensity to develop internal browning disorders.
- Braeburn with respiration rates above 6 ml CO<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> at harvest were prone to developing core flush and internal flesh breakdown
- Delayed ethylene scrubbing applied 70 days after the beginning of CA establishment (1.2% O<sub>2</sub>, <1.0% CO<sub>2</sub>) maintained background green colour in some orchard consignments that were mature at harvest
- Modulated low temperature storage (0.5-1.0°C) of Braeburn, while reducing the rate of softening in fruit from some orchard consignments, failed to control the development of internal disorders

### **Knowledge and Technology Transfer**

The project was introduced to growers at the Marden Fruit Show Society and EMRA Day in March 2010 and to the HDC Tree Fruit Panel in March 2011.

### **References**

- Cross, J.V. & Berrie, A.M. (2010). Integrated pest and disease management in apple production. In: *The Best Practice Guide for UK Apple Production*, HDC website [www.hdc.org.uk](http://www.hdc.org.uk)
- Levesque, P.G., DeEll, J.R. & Murr, D.P. (2006). Sequential controlled atmosphere storage for 'McIntosh' apples. *HortScience*, 41(5), 1322-1324.

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## APPENDICES

**Table 3.3.** December inspection (70 days) ex-store quality of Braeburn apples stored at 1.5-2.0°C or 0.5-1.0°C followed by seven days shelf life at 18°C

| Orchard                           | Firmness (N)*         |                       |                         |                         | % Brix                |                       |                         |                         |
|-----------------------------------|-----------------------|-----------------------|-------------------------|-------------------------|-----------------------|-----------------------|-------------------------|-------------------------|
|                                   | Ex-store<br>1.5-2.0°C | Ex-store<br>0.5-1.0°C | Shelf-life<br>1.5-2.0°C | Shelf-life<br>0.5-1.0°C | Ex-store<br>1.5-2.0°C | Ex-store<br>0.5-1.0°C | Shelf-life<br>1.5-2.0°C | Shelf-life<br>0.5-1.0°C |
| B                                 | 91.0                  | 91.1                  | 94.5                    | 94.2                    | 14.9                  | 14.6                  | 14.9                    | 15.5                    |
| E                                 | 94.3                  | 93.3                  | 93.3                    | 96.2                    | 13.0                  | 13.0                  | 12.8                    | 13.7                    |
| J                                 | 89.3                  | 92.4                  | 94.3                    | 91.0                    | 12.9                  | 12.9                  | 13.4                    | 13.4                    |
| Mi                                | 86.4                  | 86.0                  | 89.2                    | 93.2                    | 13.8                  | 13.7                  | 14.0                    | 13.9                    |
| My                                | 84.1                  | 85.9                  | 88.0                    | 86.2                    | 13.1                  | 13.6                  | 13.7                    | 13.3                    |
| N                                 | 95.1                  | 96.4                  | 96.9                    | 98.4                    | 13.4                  | 13.6                  | 13.5                    | 13.9                    |
| <b>LSD<sub>0.05</sub> (11 df)</b> | <b>7.47</b>           |                       | <b>4.18</b>             |                         | <b>0.57</b>           |                       | <b>0.42</b>             |                         |

To convert Newtons to kg pressure divide by 0.98 (~10)

**Table 3.4.** December inspection (70 days) ex-store quality of Braeburn apples stored at 1.5-2.0°C or 0.5-1.0°C followed by seven days shelf life at 18°C

| Orchard                           | Green colour (-a)     |                       |                         |                         | Yellow Colour (b)     |                       |                         |                         |
|-----------------------------------|-----------------------|-----------------------|-------------------------|-------------------------|-----------------------|-----------------------|-------------------------|-------------------------|
|                                   | Ex-store<br>1.5-2.0°C | Ex-store<br>0.5-1.0°C | Shelf-life<br>1.5-2.0°C | Shelf-life<br>0.5-1.0°C | Ex-store<br>1.5-2.0°C | Ex-store<br>0.5-1.0°C | Shelf-life<br>1.5-2.0°C | Shelf-life<br>0.5-1.0°C |
| B                                 | -15.6                 | -13.9                 | -14.0                   | -12.6                   | 42.1                  | 42.1                  | 44.7                    | 44.3                    |
| E                                 | -13.8                 | -14.1                 | -15.5                   | -12.8                   | 40.1                  | 41.4                  | 43.8                    | 43.3                    |
| J                                 | -14.8                 | -11.2                 | -13.0                   | -13.0                   | 42.1                  | 40.2                  | 42.7                    | 43.9                    |
| Mi                                | -14.2                 | -15.6                 | -14.3                   | -14.8                   | 40.7                  | 41.8                  | 44.2                    | 45.0                    |
| My                                | -11.4                 | -12.9                 | -12.3                   | -12.3                   | 39.7                  | 40.2                  | 42.1                    | 42.1                    |
| N                                 | -10.3                 | -11.8                 | -10.3                   | -8.2                    | 42.8                  | 44.1                  | 45.1                    | 44.5                    |
| <b>LSD<sub>0.05</sub> (11 df)</b> | <b>1.81</b>           |                       | <b>2.58</b>             |                         | <b>1.24</b>           |                       | <b>1.30</b>             |                         |

**Table 3.5.** Ex-store firmness (N) of Braeburn after 140 days of storage at 1.2% O<sub>2</sub>

| Orchard | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|---------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|         | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B       | 89.2           | 91.3      | 90.2      | 91.5      | 94.8      | 93.0      | 91.7                  | 92.3                  |
| E       | 89.1           | 91.0      | 91.6      | 91.6      | 95.5      | 88.4      | 92.1                  | 91.3                  |
| J       | 85.9           | 89.6      | 91.0      | 90.4      | 94.1      | 90.0      | 93.9                  | 89.9                  |
| Mi      | 87.5           | 89.0      | 88.7      | 91.9      | 89.7      | 90.2      | 91.0                  | 90.0                  |
| My      | 87.2           | 86.6      | 88.3      | 87.1      | 89.2      | 86.4      | 87.4                  | 86.8                  |
| N       | 91.6           | 91.1      | 92.3      | 89.4      | 96.6      | 95.3      | 93.4                  | 91.9                  |

LSD<sub>0.05</sub> (45df) 4.09

Ethylene scrubbed after 70 days storage

**Table 3.6.** Firmness (N) of Braeburn after 140 days storage at 1.2% O<sub>2</sub> plus seven days shelf-life at 18°C

| Orchard | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|---------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|         | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B       | 85.2           | 88.7      | 86.1      | 90.2      | 91.7      | 90.6      | 86.9                  | 90.7                  |
| E       | 82.2           | 93.7      | 85.5      | 90.3      | 88.0      | 90.7      | 89.5                  | 88.7                  |
| J       | 85.0           | 87.5      | 88.8      | 87.3      | 88.2      | 89.2      | 93.7                  | 86.5                  |
| Mi      | 86.6           | 87.8      | 89.5      | 90.3      | 90.4      | 88.2      | 89.9                  | 90.6                  |
| My      | 86.1           | 86.0      | 87.2      | 86.2      | 85.5      | 87.8      | 87.5                  | 88.6                  |
| N       | 82.1           | 86.0      | 84.8      | 85.0      | 88.9      | 81.7      | 89.9                  | 84.1                  |

LSD<sub>0.05</sub> (45df) 4.93

Ethylene scrubbed after 70 days storage

**Table 3.7.** Sugar content of Braeburn after 140 days of storage at 1.2% Oxygen

| Orchard                     | Ex-store Sugars (% Brix) |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C                | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 15.3                     | 15.5      | 15.8      | 15.2      | 15.7      | 15.4      | 14.9                  | 15.5                  |
| E                           | 13.6                     | 14.3      | 13.9      | 13.6      | 13.8      | 13.4      | 13.4                  | 13.4                  |
| J                           | 13.9                     | 13.2      | 13.9      | 13.6      | 13.4      | 13.5      | 14.1                  | 13.5                  |
| Mi                          | 13.9                     | 14.1      | 14.0      | 14.2      | 14.3      | 14.0      | 14.4                  | 14.2                  |
| My                          | 13.7                     | 13.8      | 13.7      | 13.8      | 14.1      | 13.7      | 13.7                  | 13.4                  |
| N                           | 13.8                     | 14.1      | 14.2      | 13.5      | 14.6      | 14.1      | 14.3                  | 14.1                  |
| LSD <sub>0.05</sub> (45 df) |                          |           |           | 0.60      |           |           |                       |                       |

**Table 3.8.** Sugar content of Braeburn after 140 days storage plus seven days at 18°C

| Orchard                     | Ex-store Sugars (% Brix) |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C                | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 14.7                     | 15.0      | 15.0      | 14.7      | 15.0      | 14.6      | 15.2                  | 14.8                  |
| E                           | 13.5                     | 13.4      | 13.7      | 13.2      | 13.1      | 13.0      | 13.8                  | 13.3                  |
| J                           | 13.1                     | 13.1      | 13.5      | 12.9      | 13.2      | 13.0      | 13.2                  | 12.9                  |
| Mi                          | 13.6                     | 13.3      | 14.1      | 13.6      | 13.8      | 13.4      | 13.8                  | 13.4                  |
| My                          | 13.5                     | 13.4      | 13.3      | 13.4      | 13.4      | 13.2      | 13.2                  | 13.2                  |
| N                           | 13.6                     | 13.2      | 14.0      | 13.6      | 13.5      | 13.6      | 13.7                  | 13.3                  |
| LSD <sub>0.05</sub> (45 df) |                          |           |           | 0.58      |           |           |                       |                       |

**Table 3.9.** Background green colour (Minolta – a) of Braeburn after 140 days of storage at 1.2% Oxygen

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | -14.7          | -11.8     | -13.3     | -13.1     | -12.9     | -13.6     | -11.6                 | -13.3                 |
| E                           | -12.9          | -13.0     | -14.2     | -10.3     | -11.0     | -12.7     | -13.8                 | -14.2                 |
| J                           | -12.3          | -13.2     | -12.7     | -13.1     | -11.8     | -12.6     | -11.9                 | -11.7                 |
| Mi                          | -13.8          | -13.1     | -14.2     | -14.3     | -13.1     | -12.6     | -13.3                 | -14.7                 |
| My                          | -10.8          | -11.3     | -10.8     | -12.0     | -12.4     | -10.5     | -12.3                 | -12.0                 |
| N                           | -10.3          | -9.7      | -10.3     | -10.2     | -9.9      | -9.9      | -9.8                  | -9.2                  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 2.82      |           |           |                       |                       |

**Table 3.10.** Background green colour (Minolta a) of Braeburn after 140 days of storage at 1.2% Oxygen plus seven days at 18°C

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | -11.1          | -12.2     | -11.8     | -13.1     | -10.7     | -12.2     | -12.4                 | -11.1                 |
| E                           | -12.0          | -12.5     | -10.3     | -12.7     | -11.1     | -12.4     | -11.1                 | -12.2                 |
| J                           | -12.7          | -11.2     | -9.5      | -11.3     | -12.3     | -11.0     | -12.9                 | -12.5                 |
| Mi                          | -12.6          | -12.6     | -12.5     | -11.4     | -12.4     | -12.0     | -12.0                 | -14.0                 |
| My                          | -10.6          | -11.1     | -9.4      | -9.6      | -9.7      | -9.8      | -11.4                 | -11.3                 |
| N                           | -8.4           | -10.4     | -9.4      | -7.5      | -8.4      | -6.4      | -10.2                 | -10.6                 |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 2.33      |           |           |                       |                       |

**Table 3.11.** Percentage rotting in Braeburn stored for 140 days at 1.2% Oxygen

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |  |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|--|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |  |
| B                           | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 0.0                   |  |
| E                           | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 5.0                   |  |
| J                           | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 5.0                   | 0.0                   |  |
| Mi                          | 0.0            | 0.0       | 5.0       | 0.0       | 5.0       | 0.0       | 0.0                   | 0.0                   |  |
| My                          | 0.0            | 0.8       | 0.0       | 5.0       | 0.0       | 5.0       | 0.0                   | 0.0                   |  |
| N                           | 0.0            | 5.0       | 5.9       | 5.0       | 15.0      | 5.0       | 10.0                  | 0.0                   |  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 7.94      |           |           |                       |                       |  |

**Table 3.12.** Percentage rotting in Braeburn stored for 140 days at 1.2% Oxygen plus seven days shelf-life at 18°C

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |  |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|--|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |  |
| B                           | 0              | 0         | 0         | 5         | 0         | 5         | 0                     | 5                     |  |
| E                           | 0              | 0         | 10        | 0         | 0         | 10        | 0                     | 0                     |  |
| J                           | 0              | 0         | 0         | 10        | 0         | 0         | 5                     | 0                     |  |
| Mi                          | 0              | 0         | 0         | 0         | 0         | 5         | 0                     | 0                     |  |
| My                          | 0              | 5         | 0         | 0         | 0         | 0         | 5                     | 0                     |  |
| N                           | 5              | 0         | 20        | 15        | 5         | 10        | 5                     | 15                    |  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 10.05     |           |           |                       |                       |  |

**Table 3.13.** Percentage core-flush in Braeburn stored for 140 days at 1.2% Oxygen

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 0.0                   |
| E                           | 0.3            | 5.0       | 0.0       | 0.0       | 0.0       | 10.0      | 0.0                   | 0.0                   |
| J                           | 0.0            | 0.0       | 0.0       | 0.0       | 5.0       | 0.0       | 10.0                  | 0.0                   |
| Mi                          | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 0.0                   |
| My                          | 0.0            | 4.6       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 0.0                   |
| N                           | 0.0            | 25.0      | 5.5       | 0.0       | 0.0       | 10.0      | 10.0                  | 0.0                   |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 7.04      |           |           |                       |                       |

**Table 3.14.** Percentage core-flush in Braeburn stores for 140 days at 1.2% O<sub>2</sub> plus seven days at 18°C

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 15.0      | 0.0                   | 0.0                   |
| E                           | 10.0           | 15.0      | 16.5      | 5.0       | 20.0      | 22.0      | 5.0                   | 5.0                   |
| J                           | 0.0            | 10.0      | 10.0      | 0.0       | 5.0       | 5.0       | 0.0                   | 0.0                   |
| Mi                          | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 0.0                   |
| My                          | 0.0            | 5.0       | 0.0       | 0.0       | 5.0       | 10.0      | 0.0                   | 0.0                   |
| N                           | 31.5           | 40.0      | 36.5      | 25.0      | 21.5      | 63.0      | 25.0                  | 50.0                  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 14.08     |           |           |                       |                       |

**Table 3.15.** Firmness (N) of Braeburn apples after 210 days at 1.2% Oxygen

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 87.3           | 88.7      | 88.1      | 85.8      | 90.9      | 91.9      | 86.9                  | 93.0                  |
| E                           | 84.3           | 86.8      | 85.8      | 85.9      | 89.9      | 90.7      | 87.0                  | 90.0                  |
| J                           | 86.0           | 83.2      | 84.3      | 87.1      | 85.3      | 86.5      | 85.8                  | 86.0                  |
| Mi                          | 84.9           | 84.9      | 85.1      | 86.0      | 85.8      | 88.1      | 83.8                  | 86.4                  |
| My                          | 80.9           | 83.8      | 83.2      | 82.5      | 85.5      | 85.5      | 81.6                  | 86.3                  |
| N                           | 85.6           | 86.2      | 85.4      | 85.0      | 88.1      | 87.5      | 88.8                  | 87.2                  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 3.74      |           |           |                       |                       |

**Table 3.16.** Firmness of Braeburn apples after 210 days at 1.2% Oxygen followed by seven days at 18°C

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 85.2           | 88.7      | 86.1      | 90.2      | 91.7      | 90.6      | 86.9                  | 90.7                  |
| E                           | 82.2           | 93.7      | 85.5      | 90.3      | 88.0      | 90.7      | 89.5                  | 88.7                  |
| J                           | 85.0           | 87.5      | 88.8      | 87.3      | 88.2      | 89.2      | 93.7                  | 86.5                  |
| Mi                          | 86.6           | 87.8      | 89.5      | 90.3      | 90.4      | 88.2      | 89.9                  | 90.6                  |
| My                          | 86.1           | 86.0      | 87.2      | 86.2      | 85.5      | 87.8      | 87.5                  | 88.6                  |
| N                           | 82.1           | 86.0      | 84.8      | 85.0      | 88.9      | 81.7      | 89.9                  | 84.1                  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 4.93      |           |           |                       |                       |

**Table 3.17.** Sugar content (% Brix) of Braeburn apples after 210 days in storage

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 14.4           | 14.4      | 14.6      | 14.7      | 15.4      | 14.7      | 15.4                  | 14.4                  |
| E                           | 13.6           | 13.0      | 13.2      | 13.4      | 13.5      | 13.2      | 13.0                  | 13.2                  |
| J                           | 13.1           | 12.7      | 13.4      | 13.5      | 13.2      | 13.4      | 13.2                  | 13.3                  |
| Mi                          | 14.0           | 13.6      | 14.3      | 13.7      | 13.7      | 13.5      | 13.4                  | 13.5                  |
| My                          | 13.4           | 13.0      | 13.0      | 13.4      | 13.4      | 13.2      | 13.1                  | 13.2                  |
| N                           | 13.9           | 13.7      | 13.5      | 13.6      | 13.7      | 13.6      | 13.7                  | 14.1                  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 0.55      |           |           |                       |                       |

**Table 3.18.** Sugar content (%Brix) of Braeburn apples after 210 days of storage

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 14.7           | 15.0      | 15.0      | 14.7      | 15.0      | 14.6      | 15.2                  | 14.8                  |
| E                           | 13.5           | 13.4      | 13.7      | 13.2      | 13.1      | 13.0      | 13.8                  | 13.3                  |
| J                           | 13.1           | 13.1      | 13.5      | 12.9      | 13.2      | 13.0      | 13.2                  | 12.9                  |
| Mi                          | 13.6           | 13.3      | 14.1      | 13.6      | 13.8      | 13.4      | 13.8                  | 13.4                  |
| My                          | 13.5           | 13.4      | 13.3      | 13.4      | 13.4      | 13.2      | 13.2                  | 13.2                  |
| N                           | 13.6           | 13.2      | 14.0      | 13.6      | 13.5      | 13.6      | 13.7                  | 13.3                  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 0.58      |           |           |                       |                       |

**Table 3.19.** Background green colour after 210 days of storage at 1.2% O<sub>2</sub>

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | -13.7          | -14.9     | -13.4     | -13.3     | -14.1     | -14.1     | -13.2                 | -14.1                 |
| E                           | -11.4          | -12.7     | -12.9     | -12.4     | -10.3     | -13.5     | -13.5                 | -12.5                 |
| J                           | -11.5          | -14.3     | -12.4     | -12.5     | -11.8     | -12.8     | -11.0                 | -13.1                 |
| Mi                          | -14.3          | -13.6     | -12.9     | -13.5     | -12.6     | -14.4     | -13.1                 | -13.6                 |
| My                          | -11.0          | -11.4     | -11.4     | -12.0     | -12.6     | -10.0     | -11.5                 | -10.5                 |
| N                           | -9.7           | -7.4      | -7.6      | -8.6      | -9.5      | -10.9     | -9.4                  | -8.1                  |
| LSD <sub>0.05</sub> (45 df) | 2.46           |           |           |           |           |           |                       |                       |

**Table 3.20.** Background green colour after 210 days of storage at 1.2% O<sub>2</sub> plus seven days at 18°C

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | -11.1          | -12.2     | -11.8     | -13.1     | -10.7     | -12.2     | -12.4                 | -11.1                 |
| E                           | -12.0          | -12.5     | -10.3     | -12.7     | -11.1     | -12.4     | -11.1                 | -12.2                 |
| J                           | -12.7          | -11.2     | -9.5      | -11.3     | -12.3     | -11.0     | -12.9                 | -12.5                 |
| Mi                          | -12.6          | -12.6     | -12.5     | -11.4     | -12.4     | -12.0     | -12.0                 | -14.0                 |
| My                          | -10.6          | -11.1     | -9.4      | -9.6      | -9.7      | -9.8      | -11.4                 | -11.3                 |
| N                           | -8.4           | -10.4     | -9.4      | -7.5      | -8.4      | -6.4      | -10.2                 | -10.6                 |
| LSD <sub>0.05</sub> (45 df) | 2.33           |           |           |           |           |           |                       |                       |

**Table 3.21.** Percentage rotting in Braeburn after 210 days of storage at 1.2% O<sub>2</sub>

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 10.0           | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 0.0                   |
| E                           | 5.0            | 2.1       | 0.0       | 0.0       | 10.0      | 0.0       | 5.0                   | 0.0                   |
| J                           | 5.0            | 5.0       | 15.0      | 0.0       | 5.0       | 0.0       | 0.0                   | 5.0                   |
| Mi                          | 5.0            | 0.0       | 0.0       | 0.0       | 5.0       | 0.0       | 0.0                   | 0.0                   |
| My                          | 0.0            | 5.0       | 0.0       | 10.0      | 0.0       | 0.0       | 0.0                   | 10.0                  |
| N                           | 10.0           | 5.0       | 0.0       | 25.0      | 10.0      | 0.0       | 15.0                  | 0.0                   |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 11.17     |           |           |                       |                       |

**Table 3.22.** % Rots after 210 days of storage at 1.2% O<sub>2</sub> followed by seven days at 18°C

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |
| B                           | 0.0            | 0.0       | 0.0       | 5.0       | 0.0       | 5.0       | 0.0                   | 5.0                   |
| E                           | 0.0            | 0.0       | 10.0      | 0.0       | 0.0       | 10.0      | 0.0                   | 0.0                   |
| J                           | 0.0            | 0.0       | 0.0       | 10.0      | 0.0       | 0.0       | 5.0                   | 0.0                   |
| Mi                          | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 5.0       | 0.0                   | 0.0                   |
| My                          | 0.0            | 5.0       | 0.0       | 0.0       | 0.0       | 0.0       | 5.0                   | 0.0                   |
| N                           | 5.0            | 0.0       | 20.0      | 15.0      | 5.0       | 10.0      | 5.0                   | 15.0                  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 11.17     |           |           |                       |                       |

**Table 3.23.** The incidence of core flush (%) after 210 days of storage at 1.2% O<sub>2</sub>

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |  |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|--|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |  |
| B                           | 0.0            | 5.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 0.0                   |  |
| E                           | 5.0            | 3.0       | 0.0       | 0.0       | 5.5       | 5.0       | 0.0                   | 5.0                   |  |
| J                           | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 0.0                   |  |
| Mi                          | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                   | 5.0                   |  |
| My                          | 0.0            | 0.0       | 0.0       | 0.0       | 10.0      | 0.0       | 0.0                   | 0.0                   |  |
| N                           | 10.0           | 5.0       | 15.0      | 0.0       | 5.0       | 10.0      | 11.5                  | 0.0                   |  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 8.3       |           |           |                       |                       |  |

**Table 3.24.** The incidence of core flush (%) after 210 days of storage at 1.2% O<sub>2</sub> and following seven days shelf-life

| Orchard                     | Temperature °C |           |           |           |           |           | Scrubbed<br>1.5/1.5°C | Scrubbed<br>0.5/0.5°C |  |
|-----------------------------|----------------|-----------|-----------|-----------|-----------|-----------|-----------------------|-----------------------|--|
|                             | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C |                       |                       |  |
| B                           | 0              | 0         | 0         | 0         | 0         | 15        | 0                     | 0                     |  |
| E                           | 10             | 15        | 16.5      | 5         | 20        | 22        | 5                     | 5                     |  |
| J                           | 0              | 10        | 10        | 0         | 5         | 5         | 0                     | 0                     |  |
| Mi                          | 0              | 0         | 0         | 0         | 0         | 0         | 0                     | 0                     |  |
| My                          | 0              | 5         | 0         | 0         | 5         | 10        | 0                     | 0                     |  |
| N                           | 31.5           | 40        | 36.5      | 25        | 21.5      | 63        | 25                    | 50                    |  |
| LSD <sub>0.05</sub> (45 df) |                |           |           | 14.08     |           |           |                       |                       |  |

**Table 3.25.** Percentage of senescent breakdown after 210 days of storage at 1.2% O<sub>2</sub>

| Orchard                        | Temperature °C |           |           |           |           |           |                    |                    |
|--------------------------------|----------------|-----------|-----------|-----------|-----------|-----------|--------------------|--------------------|
|                                | 1.5/1.5°C      | 1.5/1.5°C | 1.5/0.5°C | 0.5-1.5°C | 0.5/0.5°C | 0.5-0.5°C | Scrubbed 1.5/1.5°C | Scrubbed 0.5/0.5°C |
| B                              | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 5.0       | 0.0                | 0.0                |
| E                              | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                | 0.0                |
| J                              | 0.0            | 0.0       | 0.0       | 5.0       | 10.0      | 15.0      | 0.0                | 5.5                |
| Mi                             | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                | 0.0                |
| My                             | 0.0            | 0.0       | 0.0       | 0.0       | 0.0       | 0.0       | 0.0                | 0.0                |
| N                              | 10.0           | 10.0      | 10.0      | 65.5      | 51.5      | 40.0      | 0.0                | 45.0               |
| LSD <sub>0.05</sub><br>(45 df) | 5.32           |           |           |           |           |           |                    |                    |