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|---|---|
| **Project title** | Effects of store oxygen concentration and rate of establishment of low oxygen conditions on the quality of Braeburn apples |
| **Project number:** | TF175 |
| **Project leader:** | David Johnson, EMR |
| **Report:** | Final report, June 2009 |
| **Previous report** | Annual report, May 2008 |
| **Key staff:** | Karen Thurston<br>Clare Hopson |
| **Location of project:** | EMR |
| **Project coordinator:** | Andrew Tinsley, HDC |
| **Date project commenced:** | 1.7.07 |
| **Date project completed (or expected completion date):** | 30.6.09 |
| **Key words:** | apple, storage, Braeburn, CA |

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The results and conclusions in this report are based on an investigation conducted over a two-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

**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.

David Johnson
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## Grower Summary

### Headlines

- Longer storage of Braeburn may be possible for orchard / sites with low potential for core flush and breakdown picked at the correct stage of maturity
- Changes in store management conferred advantages for fruit quality and reduced the development of physiological disorders such as core flush, breakdown and scald.

### Background and expected deliverables

Previous research funded by the HDC (TF152) and carried out in collaboration with Worldwide Fruit and FAST Ltd under the auspices of the Quality Fruit Group (supported by English Apples and Pears Ltd) established the minimum storage temperature for Braeburn and the maximum duration of storage in air and controlled atmosphere (CA) conditions of 2% $O_2$ and <1% $CO_2$. In addition maturity parameters were established for the harvesting of Braeburn at a stage that maximized visual and eating quality and avoided the development of superficial scald. Clonal differences in storage behaviour were also described.

Within the 3 years of project TF152 it was not possible to evaluate fully the effects of storing Braeburn apples in 1.2% $O_2$ as opposed to 2% $O_2$, or the consequences of sealing CA stores immediately after loading as opposed to a 3-week delay as recommended in countries abroad for the avoidance of Braeburn Browning Disorder (BBD) a disorder associated with low oxygen and / or high carbon dioxide in the tissues of the fruit.

Growers are concerned about the time taken to establish CA conditions where stores are sealed 3 weeks after loading. Since the majority of growers do not have nitrogen gas available for flushing stores to rapidly achieve low oxygen conditions, the low respiration rate of Braeburn apples held at 1.5-2$^{o}$C may reduce store oxygen by less than 1% per day and some loss of quality and storage life may be expected as a consequence. More importantly the impact of slow establishment of CA conditions on the development of core flush is unknown. The occurrence of this disorder currently limits the storage of

Braeburn to March which is well short of commercial marketing targets of April and possibly May. Any change in the protocol for storing UK Braeburn that minimizes the risk of core flush would be welcomed by growers and marketing organizations.

Without nitrogen flushing the reduction in store oxygen concentration in commercial stores will depend on the innate respiration of the consignments and the gas tightness of the stores. Research was proposed to determine positive and negative effects of establishing low oxygen conditions immediately after cooling by nitrogen flushing or gradually by respiration. Different rates of oxygen reduction by respiration were established to accommodate the likely range in establishment times achieved in commercial stores. Different rates of oxygen 'pull-down' were compared on stores sealed immediately after cooling and after a 3-week delay. Final oxygen concentrations were maintained at the recommended 2% $O_2$ and at 1.2% $O_2$. It was important to investigate possible interactions between the delay and rate of CA establishment and the oxygen concentration used for storage of the fruit.

It was intended that the research would provide clear guidelines to growers on how to establish CA conditions in stores of Braeburn and to alleviate current concerns about the time taken to establish CA using current best practice.

**Summary of the project and main conclusions**

***Year 1***

A 3-year-old commercial Braeburn orchard (Hillwell clone) in West Kent was selected for the study. Samples of fruit for storage were picked on the 4 and 10 October 2007. At each pick 70 fruits were selected at random from each of 30 trees. After picking all fruit was transported immediately to the Jim Mount Building at EMR. Sixty four 30-fruit samples were formed by placing into a net one fruit from each of the 30 boxes and repeating the exercise. In this way each sample had a fruit from each of the 30 trees sampled in the orchard. All nets were labeled and weighed and placed into a store at 1.5$^{o}$C to cool overnight. The next day samples were allocated to 360 L storage containers (8 samples to each of 8 containers). Four containers were sealed immediately and the remaining four after 21 days (current recommended practice). For containers sealed immediately and after 21 days there were four rates of CA establishment. Nitrogen was injected into the containers at rates that lowered the oxygen

concentration to 2% in 1 hour or within 7, 10 or 14 days. When 2% $O_2$ was reached half of the samples were transferred to a lower oxygen (1.2% $O_2$) atmosphere whilst the remaining samples continued in a 2% $O_2$ regime. The entire exercise was repeated for the second pick of fruit. The treatments applied in 2007 are summarized as follows:

**Table 1. 2007 treatments**

| Pick | Delay to seal (days) | Days to establish 2% $O_2$ | | | | Store oxygen conc. | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 1 (4.10.07) | 0 | 0 | 7 | 10 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| | 21 | 0 | 7 | 10 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| 2 (10.10.07) | 0 | 0 | 7 | 10 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| | 21 | 0 | 7 | 10 | 14 | 2% $O_2$ | 1.2% $O_2$ |

Throughout CA establishment and storage the $CO_2$ concentration was maintained below 1% by the use of hydrated lime scrubbers. Oxygen concentrations were maintained at 1.2 or 2% by automated injection of compressed air and fruit temperature was maintained at 1.5-2$^{o}$C. Gas measurement and control was achieved using an ICA 66 system (International Controlled Atmosphere Ltd).

Fruit was removed from the containers for quality assessment on 21 and 22 January and 7 and 9 April 2008. Quality was assessed immediately ex-store and again after a further 7 days at 20$^{o}$C.

There was no tissue damage in the fruit regardless of when the CA containers were sealed or how quickly the CA conditions were established. Therefore it appeared that UK-grown Braeburn is not as susceptible to BBD to those grown abroad.

The ability to seal stores after loading and cooling rather than after a 3-week delay conferred advantages in terms of fruit quality. Firmness and green background colour was maintained more effectively by sealing the storage containers immediately after cooling as opposed to delaying sealing by 21 days. More importantly there was a three-fold reduction in the amount of core flush by immediate sealing of the CA containers compared with a 3-week delay. This is particularly important since the development of

core flush currently determines the termination date of Braeburn as March. There is a major commercial incentive to extend the marketing of Braeburn into April and possibly May.

The different rates of CA establishment had little effect on the storage quality of Braeburn in 2007-8. It was anticipated that more rapid establishment of CA conditions would be beneficial to retention of green colour and firmness but this was not the case.

Storing in 1.2% $O_2$ as opposed to 2% $O_2$ reduced weight loss and stickiness of fruit and provided greener, firmer fruit compared with 2% $O_2$.

As expected, fruits from the second harvest were softer and more yellow than those from the first harvest, even though fruit at both picks were at a slightly less mature stage than is considered ideal. However, the overall quality of fruit from both picks was more than acceptable in April with firmness 7.8 (pick 1) and 7.6 kg (pick 2) and greenness of 1.8 and 2.0 respectively (commercial colour chart where 1 is green and 4 is yellow).

***Year 2***

Four commercial Braeburn orchards (Hillwell clone) were selected for the study. These included the orchard in West Kent (Marden) used in the first year of the study. The additional orchards were located in West Kent (West Malling), North Kent (Upchurch) and East Kent (Hernhill). Samples of fruit for storage were picked on 10 and 24 October 2008. At each pick and in each orchard one thousand fruits were picked at random from at least 12 trees in a single row. Sub-samples (two replicate samples of 10 fruit) were taken from the picked fruit for assessment of fruit maturity. After picking all fruit was transported immediately to the Jim Mount Building at EMR and placed in to a holding cold store (1.5$^{o}$C) overnight. The following day the fruit from each orchard was used to form forty-eight 20-fruit samples. Each sample had an equivalent number of fruits from each of the trees sampled in the orchard. All nets were labeled and weighed and allocated to 360 L storage containers (32 samples to each of 6 containers). Three containers were sealed immediately and the remaining three after 21 days (current recommended practice). For containers sealed immediately and after 21 days there were three rates of CA establishment. Nitrogen was injected into the containers at rates that lowered the oxygen concentration to 2% in 1 hour or within 7 or 14 days. When 2%

$O_2$ was reached half of the samples were transferred to a lower oxygen (1.2% $O_2$) atmosphere whilst the remaining samples continued in a 2% $O_2$ regime. The entire exercise was repeated for the second pick of fruit. The treatments applied in 2008 are summarized as follows:

**Table 2 . 2008 treatments**

| Pick | Delay to seal (days) | Days to establish 2% $O_2$ | | | Store oxygen conc. | |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 (10.10.08) | 0 | 0 | 7 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| | 21 | 0 | 7 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| 2 (24.10.08) | 0 | 0 | 7 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| | 21 | 0 | 7 | 14 | 2% $O_2$ | 1.2% $O_2$ |

Throughout CA establishment and storage $CO_2$ concentrations were maintained below 1% by the use of hydrated lime scrubbers. Oxygen concentrations were maintained at 1.2 or 2% by automated injection of compressed air and fruit temperature was maintained at 1.5-2$^{o}$C. Gas measurement and control was achieved using an ICA 66 system (International Controlled Atmosphere Ltd).

Fruit was removed from the containers for quality assessment on 2-6 March and 28 April – 7 May 2009. Quality was assessed immediately ex-store and again after a further 7 days at 20$^{o}$C

It was expected that there would be significant benefits of achieving CA conditions more rapidly and by maintaining lower concentrations of oxygen during the storage period. This is consistent with general storage advice provided in the UK Best Practice Guide for UK Apple Production (2001) (currently under revision by the HDC).

In both years of the project the sealing of storage containers immediately after cooling as opposed to a delay of 21 days (currently recommended and based on a perceived risk of BBD and brownheart) conferred advantages for fruit quality. Firmness and green background colour was maintained more effectively by sealing the storage containers

immediately after cooling as opposed to delaying sealing by 21 days. The subsequent rate of establishing CA conditions (0, 7, 10 and 14 days in 2007 and 0, 7 and 14 days in 2008) had little or no effects on retention of greenness or firmness but storing in 1.2% $O_2$ as opposed to 2% $O_2$ provided greener, firmer fruit in both years.

Although it is important to maximise the visual and eating quality of Braeburn throughout storage the current limitations in storage life relate primarily to the development of physiological disorders such as core flush and flesh breakdown. The 2008 experiment showed clearly the increased development of disorders in the final two months of storage. From early March to late April the incidence of core flush virtually doubled, flesh breakdown was more problematic and a low incidence of scald was recorded in fruit stored until late April and subjected to a simulated marketing period.

The main focus of the project was to assess the prospect for amelioration of these disorders through modification of storage practice. The results of work done in Year 1 of the project were very encouraging. In fruit from a single orchard a 3-fold reduction in core flush incidence was achieved by sealing stores immediately after cooling as opposed to a delay of 21 days. In Year 2 immediate sealing of storage containers resulted in a 2-fold reduction in core flush incidence in fruit removed from store in March but the effect was lost when storage was extended to late April and when fruit was kept in simulated marketing conditions. However, immediate sealing was beneficial in terms of reducing flesh breakdown in fruit stored until April.

Although it was anticipated that that a more rapid rate of establishing CA conditions might be beneficial to retention of green colour and firmness this was not the case in the 2007 experiment and there were only slight benefits on these quality parameters in the 2008 experiment. More rapid establishment offered no advantage in terms of reducing the development of disorders.

Maintaining store oxygen concentrations at 1.2% as opposed to the currently recommended 2% was advantageous. Fruit stored in the lower oxygen regime lost less weight, retained a greener background colour and higher firmness and developed less core flush. The low incidence of scald that developed in fruit stored until late April and

subjected to a further 7 days at 20°C was restricted to fruit in the higher (2%) concentration of oxygen.

Although changes in store management resulted in some positive effects on fruit quality **these were often slight when compared the marked influence of orchard site**. It is clear that to extend the storage of Braeburn to late April or early May growers need to be aware of the storage behaviour of fruits from their orchards and to accumulate data over a number of seasons. There is no knowledge of site factors that influence susceptibility of fruits to core flush in Braeburn and results from this and a previous project suggest no consistent effect of harvest date. Further research would be required to study the effects of pre-harvest (orchard and climatic) factors on susceptibility of Braeburn to core flush and flesh breakdown.

In this study there was no attempt to study effects of clones on storage quality. The Hillwell clone was chosen since this seems to be the one favoured by English growers. In previous HDC-funded work (TF 152) Lochbuie was more affected by core flush than Hillwell or Schneider.

**Conclusions**

On the basis of the results obtained in the two years of the project it is clear that changes in store management could be advocated that would benefit the quality of fruit and increase the possibility of extending the storage period beyond early March. In particular it is clear that advantages accrue from sealing stores immediately after the fruit has cooled to final holding temperature (1.5-2°C) and from storing in 1.2% oxygen rather 2%. However, there remains a concern that implementing a more stringent store management regime may induce BBD or brownheart in the fruit. Despite no brownheart occurring in the 2007 experiment and only to a very slight extent in 2 of the 4 orchards studied in the 2008 experiment it is advised that growers carry out further testing of this modified storage protocol before it is implemented on a wider scale. It is imperative that only fruit of an appropriate maturity for long-term storage is subjected to this revised protocol. Late picked fruit are likely to respond adversely and may develop $CO_2$-related injuries. The results of this project relate only to the Hillwell clone of Braeburn and to the specified harvest maturity of fruits. Where storage beyond early March is not a requirement for particular growers then the current storage protocol (delayed sealing of

stores by 21 days and storage in 2% oxygen) is advised particularly when fruit is picked later than recommended.

**Financial benefits**

Improvement in the storage quality of Braeburn will consolidate the position of UK fruit in the market place and will give UK growers a strong competitive edge against imports from Italy and France in particular. With increasing production (estimates of 20,000 tonnes by 2010) it will be vital to extend the marketing period into March and April in order to control the market and stabilise prices. This research to optimise quality and extend the period of storage has important financial implications to UK Braeburn growers and the UK fruit industry in general.

**Action points for growers**

1 Monitor and record the storage performance of fruit from all orchards every year.
2 Construct a league table to indicate orchards / farms that have the best prospects for late storage. This should be based primarily on lowest risk of disorders such as core flush and flesh breakdown.
3 The Lochbuie clone may not be suitable for extended storage as it appears to be more susceptible to core flush than Hillwell or Schneider.
4 Pick within the maturity 'window' advised by the Quality Fruit Group and preferably at the beginning of the 'window'.
5 Do not treat with SmartFresh™ as this will exacerbate risk of core flush
6 On a limited scale to start with seal stores after fruit has cooled to the final holding temperature (1.5-2°C).
7 Allow oxygen to reduce naturally by respiration. Do not accelerate by the use of nitrogen flushing.
8 Scrub carbon dioxide to maintain levels as close to zero as possible but at least to less than 1%.
9 Operate stores at 2% oxygen for at least a week before lowering to 1.2%.
10 Monitor the quality of the fruit carefully. More frequent monitoring is advised from early March. It is particularly important to subject the fruit to a simulated marketing period such as 7 days at 20°C as this is when disorders are likely to be first seen.
11 Market fruit promptly and cool chain where possible.

## Science Section

### Introduction

Previous research funded by the HDC (TF152) and carried out in collaboration with Worldwide Fruit and FAST Ltd under the auspices of the Quality Fruit Group (supported by English Apples and Pears Ltd) established the minimum storage temperature for Braeburn and the maximum duration of storage in air and controlled atmosphere (CA) conditions of 2% $O_2$ and <1% $CO_2$. In addition, maturity parameters were established for the harvesting of Braeburn at a stage that maximized visual and eating quality and avoided the development of superficial scald. Clonal differences in storage behaviour were also described.

Within the 3 years of project TF152 it was not possible to evaluate fully the effects of storing Braeburn apples in 1.2% $O_2$ as opposed to 2% $O_2$ or the consequences of sealing CA stores immediately after loading as opposed to a 3-week delay as recommended in countries abroad for the avoidance of Braeburn Browning Disorder (BBD).

Growers are concerned about the time taken to establish CA conditions where stores are sealed 3 weeks after loading. Since the majority of growers do not have nitrogen gas available for flushing stores to rapidly achieve low oxygen conditions, the low respiration rate of Braeburn apples held at 1.5-2$^{o}$C may reduce store oxygen by less than 1% per day and some loss of quality and storage life may be expected as a consequence. More importantly the impact of slow establishment of CA conditions on the development of core flush is unknown. The occurrence of this disorder currently limits the storage of Braeburn to March which is well short of commercial marketing targets of April and possibly May. Any change in the protocol for storing UK Braeburn that minimizes the risk of core flush would be welcomed by growers and marketing organizations.

Without nitrogen flushing the reduction in store oxygen concentration in commercial stores will depend on the innate respiration of the consignments and the gas tightness of the stores. Research was proposed to determine positive and negative effects of establishing low oxygen conditions immediately after cooling by nitrogen flushing or

gradually by respiration. Different rates of oxygen reduction by respiration were achieved to accommodate the likely range in establishment times achieved in commercial stores. Different rates of oxygen 'pull-down' were compared on stores sealed immediately after cooling and after a 3-week delay. Final oxygen concentrations were maintained at the recommended 2% $O_2$ and at 1.2% $O_2$. It was important to investigate possible interactions between the delay and rate of CA establishment and the oxygen concentration used for storage of the fruit.

It was intended that the research would provide clear guidelines to growers on how to establish CA conditions in stores of Braeburn and to alleviate current concerns about the time taken to establish CA using current best practice.

**Materials and methods**

***Year 1***

A 3-year-old commercial Braeburn orchard (Hillwell clone) in West Kent was selected for the study. Samples of fruit for maturity assessment were picked on 20 and 27 September and on 3 October 2007 (Table 1).

**Table 1. Maturity parameters of Braeburn (Hillwell) apples sampled from a commercial orchard in 2007. Figures for the first three picks are mean values for 20-fruit samples (1 fruit selected at random from 20 trees within a row). Figures for the picks for storage (4 and 10 October) are means values for 30-fruit samples randomized from the picked crop.**

| Pick date | Mean Fruit Weight (g) | Firmness (kg) | Soluble solids (%) | Starch cover | |
|---|---|---|---|---|---|
| | | | | Ctifl | % black |
| 20.9.07 | 130 | 10.8 | 10.0 | 1.9 | 95 |
| 27.9.07 | 146 | 10.2 | 10.6 | 2.4 | 92 |
| 3.10.07 | 148 | 9.8 | 10.5 | 2.8 | 89 |
| 4.10.07 | 151 | 9.7 | 10.4 | 2.9 | 88 |
| 10.10.07 | 148 | 9.7 | 11.2 | 3.2 | 87 |

On the basis of these tests it was decided to harvest fruit for storage on the 4 October 2007. The intention was to carry out the first pick at 80% starch and the second pick at 75% starch in accordance with the recommendations from HDC project TF152. However, the need to obtain two picks of fruit within the growers' intended picking program resulted in the first pick being slightly less mature than ideal. The second pick on 10 October coincided with the grower harvesting for storage, but even then the fruit was slightly less mature than recommended for storage.

Seventy fruits were selected at random from each of 30 trees. After picking all fruit was transported immediately to the Jim Mount Building at EMR. Sixty-four 30-fruit samples were formed by placing into a net one fruit from each of the 30 boxes and repeating the exercise. In this way each sample had a fruit from each of the 30 trees sampled in the orchard. All nets were labeled and weighed and placed into a store at 1.5$^{o}$C to cool overnight. The next day samples were allocated to 360 L storage containers (8 samples to each of 8 containers). Four containers were sealed immediately and the remaining four after 21 days (current recommended practice).

For containers sealed immediately and after 21 days there were four rates of CA establishment. Nitrogen was injected into the containers at rates that lowered the oxygen concentration to 2% in 1 hour or within 7, 10 or 14 days. When 2% $O_2$ was reached half of the samples were transferred to a lower oxygen (1.2% $O_2$) atmosphere whilst the remaining samples continued in a 2% $O_2$ regime. The entire exercise was repeated for the second pick of fruit. The treatments applied in 2007 are summarized as follows:

**Table 2. 2007 treatments**

| Pick | Delay to seal (days) | Days to establish 2% $O_2$ | | | | Store oxygen conc. | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 1 (4.10.07) | 0 | 0 | 7 | 10 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| | 21 | 0 | 7 | 10 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| 2 (10.10.07) | 0 | 0 | 7 | 10 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| | 21 | 0 | 7 | 10 | 14 | 2% $O_2$ | 1.2% $O_2$ |

Throughout CA establishment and storage $CO_2$ concentrations were maintained below 1% by the use of hydrated lime scrubbers. Oxygen concentrations were maintained at 1.2 or 2% by automated injection of compressed air and fruit temperature was maintained at 1.5-2°C. Gas measurement and control was achieved using an ICA 66 system (International Controlled Atmosphere Ltd).

Fruit was removed from the containers for quality assessment on 21 and 22 January and 7 and 9 April 2008. Quality was assessed immediately ex-store and again after a further 7 days at 20°C.

Measurements on samples taken at harvest for maturity assessment included firmness, soluble solids concentration and starch staining pattern. Details of the assessment methods are given below. Work was carried out in accordance with EMR experimental procedures and protocols. Smith (1985) has described many of the objective methods used for the assessments of quality in apples.

Fruit firmness. Two measurements were made on the opposite sides of each fruit using an LRX (Lloyd Instruments) materials testing machine fitted with an 11 mm probe. Measurements were made in the equatorial region after removal of the peel. Firmness was the maximum force (N) recorded during the insertion of the probe to a depth of 8 mm.

Soluble solids concentration. Juice was extracted from each apple using a 'Chylofel' (Copa - Technologie S.A.) apparatus and mixed to form a composite sample. Soluble solids concentration (%) was measured using a PR-32a digital refractometer (Atago Ltd).

Starch test. Half of each apple cut for internal examination was dipped in a solution containing 0.1% w/v iodine and 4% w/v potassium iodide. Dipped sections were left for at least an hour before being assessed. Each apple was scored (1-slight central discoloration to10-no peripheral discoloration) using the starch conversion chart for apples (circular type) issued by Ctifl, France. An average score was calculated for each sample and an approximation made of the percentage of the surface stained black.

Background colour. The colour of the non-blush side of the fruit was assessed using commercial (Worldwide Fruit / Qualytech) colour charts. Background colour of each fruit was compared against four cards that range from green (1) to yellow (4). The average score was calculated for each sample.

On removal from store each sample was weighed and each fruit was examined externally for the presence of rotting and external physiological disorders such as superficial scald. In January only a subjective assessment was made of the greasiness of the skin. Background colour was assessed on as many of the fruits in the sample as possible. On some fruits the extent of the red coloration was such that no measurement of background colour was possible. Firmness was measured on 10 fruits per sample and these were then cut and examined for internal physiological disorders. The remaining fruit (20) in each sample were placed into 20$^{o}$C and examined after 7 days.

***Year 2***

Four commercial Braeburn orchards (Hillwell clone) were selected for the study. These included the orchard in West Kent (Marden) used in the first year of the study. The additional orchards were located in West Kent (West Malling), North Kent (Upchurch) and East Kent (Hernhill). Samples of fruit for storage were picked on 10 and 24 October 2008. At each pick and in each orchard one thousand fruits were picked at random from at least 12 trees in a single row. Sub-samples (two replicate samples of 10 fruit) were taken from the picked fruit for assessment of fruit maturity. After picking all fruit was transported immediately to the Jim Mount Building at EMR and placed in to a holding cold store (1.5$^{o}$C) overnight.

The following day the fruit from each orchard was used to form forty-eight 20-fruit samples. Each sample had an equivalent number of fruits from each of the trees sampled in the orchard. All nets were labeled and weighed and allocated to 360 L storage containers (32 samples to each of 6 containers). Three containers were sealed immediately and the remaining three after 21 days (current recommended practice).

For containers sealed immediately and after 21 days there were three rates of CA establishment. Nitrogen was injected into the containers at rates that lowered the oxygen concentration to 2% in 1 hour or within 7 or 14 days. When 2% $O_2$ was reached half of

the samples were transferred to a lower oxygen (1.2% $O_2$) atmosphere whilst the remaining samples continued in a 2% $O_2$ regime. The entire exercise was repeated for the second pick of fruit. The treatments applied in 2008 are summarized as follows:

**Table 3. 2008 treatments**

| Pick | Delay to seal (days) | Days to establish 2% $O_2$ | | | Store oxygen conc. | |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 (10.10.08) | 0 | 0 | 7 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| | 21 | 0 | 7 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| 2 (24.10.08) | 0 | 0 | 7 | 14 | 2% $O_2$ | 1.2% $O_2$ |
| | 21 | 0 | 7 | 14 | 2% $O_2$ | 1.2% $O_2$ |

Throughout CA establishment and storage $CO_2$ concentrations were maintained below 1% by the use of hydrated lime scrubbers. Oxygen concentrations were maintained at 1.2 or 2% by automated injection of compressed air and fruit temperature was maintained at 1.5-2$^{o}$C. Gas measurement and control was achieved using an ICA 66 system (International Controlled Atmosphere Ltd). Fruit was removed from the containers for quality assessment on 2-6 March and 28 April – 7 May 2009. Quality was assessed immediately ex-store and again after a further 7 days at 20$^{o}$C.

***Statistical analysis***

All data were subjected to an analysis of variance (ANOVA) using a treatment structure to compare the effects of the treatments and any possible interactions. The overall treatment means presented in the tables can be compared using the least significant differences (LSD) provided. These were calculated at the 5% level of probability

## Results

### *Year 1*

### *Firmness*

Firmness was maintained more effectively by sealing the storage containers immediately after cooling as opposed to delaying sealing by 21 days. Delaying harvest and maintaining a higher store oxygen concentration resulted in softer fruit but there was no effect of the rate at which store oxygen concentrations were achieved. Overall firmness declined from January to April by 8.7 N (0.9 kg). In April the firmest fruit was that picked on the first occasion that was not subjected to delay in sealing and was stored in 1.2% $O_2$.

**Table 4. Effect of harvest date, delay in sealing CA containers, store oxygen concentration and storage duration on the firmness (N) of Braeburn apples. Data are mean values for fruit subjected to four different rates of establishment of CA conditions (see text).**

| | | Firmness (N) | | | |
|---|---|---|---|---|---|
| | | 2% $O_2$ | | 1.2% $O_2$ | |
| | | January | April | January | April |
| 4.10.07 | 0 days | 86.2 | 78.9 | 87.5 | 80.2 |
| | 21 days | 82.4 | 72.1 | 84.0 | 75.0 |
| 10.10.07 | 0 days | 85.2 | 73.1 | 86.6 | 80.0 |
| | 21 days | 81.3 | 71.8 | 82.0 | 74.4 |
| LSD | | 1.42 | 1.86 | 1.42 | 1.86 |

### *Weight loss*

The weight loss of fruits stored until January was highest in fruits from the second pick and was reduced by storing in 1.2 as opposed to 2% $O_2$. However, there was a strong interaction between these treatments whereby 1.2% $O_2$ reduced weight loss only in fruit from the second pick. Average weight loss increased from January to April by 0.6% and again higher weight loss was recorded in the later harvested fruit and in fruit stored in 2% $O_2$. Unlike in January there was no significant interaction between harvest date and store oxygen concentration.

**Table 5. Effect of harvest date, delay in sealing CA containers, store oxygen concentration and storage duration on the weight loss (%) of Braeburn apples. Data are mean values for fruit subjected to four different rates of establishment of CA conditions (see text).**

| | | Weight loss (%) | | | |
|---|---|---|---|---|---|
| | | 2% $O_2$ | | 1.2% $O_2$ | |
| | | January | April | January | April |
| 4.10.07 | 0 days | 0.7 | 1.6 | 0.6 | 0.9 |
| | 21 days | 0.7 | 1.6 | 0.7 | 1.1 |
| 10.10.07 | 0 days | 1.3 | 2.0 | 1.0 | 1.3 |
| | 21 days | 1.4 | 2.1 | 1.0 | 1.3 |
| LSD | | 0.09 | 0.34 | 0.09 | 0.34 |

***Background colour***

Although there were some highly significant treatment effects on the background colour of the fruits, the differences were likely to be regarded as slight from a commercial perspective. Delaying the sealing of the CA containers resulted in a more yellow background of fruits removed from store in January and April. The second harvest of fruit was more yellow than the first and storing in 1.2% $O_2$ resulted in greener fruit compared with 2% $O_2$.

**Table 6. Effect of harvest date, delay in sealing CA containers, store oxygen concentration and storage duration on the background colour (1, green to 4, yellow) of Braeburn apples. Data are mean values for fruit subjected to four different rates of establishment of CA conditions (see text).**

| | | Background colour (1, green to 4, yellow) | | | |
|---|---|---|---|---|---|
| | | 2% $O_2$ | | 1.2% $O_2$ | |
| | | January | April | January | April |
| 4.10.07 | 0 days | 1.7 | 1.8 | 1.6 | 1.7 |
| | 21 days | 1.8 | 2.0 | 1.8 | 1.9 |
| 10.10.07 | 0 days | 1.8 | 2.1 | 1.7 | 1.8 |
| | 21 days | 2.0 | 2.0 | 1.9 | 2.0 |
| LSD | | 0.09 | 0.11 | 0.09 | 0.11 |

***Core Flush***

Core flush was not present in fruit removed from store in January although the disorder developed to a slight extent (average 3%) during 7 days at 20°C. The greater incidence and severity of core flush in fruit removed in April provides a more substantial data set to test the effects of the various treatments. Consequently only the effects of treatments on core flush incidence and severity at the April examination will be reported here.

The only significant effect on core flush incidence was the three-fold increase due to the 21-day delay in sealing the CA containers. The delay also increased the average severity of core flush from 1.8 to 4.8. After 7 days at 20°C the average incidence and severity of core flush had risen from 15 to 20% and the severity index from 3.3 to 4.3.

Delay in sealing the CA containers resulted in a two-fold increase in core flush incidence and the number of fruit affected by the disorder was also increased in fruit from the first pick. Effects of treatments on core flush severity were similar to those described for core flush incidence. There was no effect of rate of CA establishment or store oxygen concentration on the incidence and severity of core flush.

**Table 7. Effect of harvest date, delay in sealing CA containers, store oxygen concentration and storage duration on the incidence (%) of core flush in Braeburn apples immediately ex-store. Data are mean values for fruit subjected to four different rates of establishment of CA conditions (see text).**

| | | Core flush (%) | | | |
|---|---|---|---|---|---|
| | | 2% $O_2$ | | 1.2% $O_2$ | |
| | | January | April | January | April |
| 4.10.07 | 0 days | 0.0 | 8.8 | 0.0 | 12.5 |
| | 21 days | 0.0 | 31.3 | 0.0 | 17.5 |
| 10.10.07 | 0 days | 0.0 | 5.0 | 0.0 | 3.8 |
| | 21 days | 0.0 | 17.5 | 0.0 | 23.8 |
| LSD | | - | 12.7 | - | 12.7 |

**Table 8. Effect of harvest date, delay in sealing CA containers, store oxygen concentration and storage duration on the severity of core flush (max. 60) in Braeburn apples immediately ex-store. Data are mean values for fruit subjected to four different rates of establishment of CA conditions (see text).**

| | | Core flush (severity index max. 60) | | | |
|---|---|---|---|---|---|
| | | 2% $O_2$ | | 1.2% $O_2$ | |
| | | January | April | January | April |
| 4.10.07 | 0 days | 0.0 | 2.3 | 0.0 | 2.5 |
| | 21 days | 0.0 | 7.0 | 0.0 | 3.5 |
| 10.10.07 | 0 days | 0.0 | 1.3 | 0.0 | 1.0 |
| | 21 days | 0.0 | 3.8 | 0.0 | 5.0 |
| LSD | | - | 2.70 | - | 2.70 |

**Table 9. Effect of harvest date, delay in sealing CA containers, store oxygen concentration and storage duration on the incidence (%) of core flush in Braeburn apples subjected to 7 days at 20°C after storage. Data are mean values for fruit subjected to four different rates of establishment of CA conditions (see text).**

| | | Core flush (%) | | | |
|---|---|---|---|---|---|
| | | 2% $O_2$ | | 1.2% $O_2$ | |
| | | January | April | January | April |
| 4.10.07 | 0 days | 3.1 | 20.0 | 1.9 | 15.3 |
| | 21 days | 6.3 | 35.2 | 1.9 | 32.4 |
| 10.10.07 | 0 days | 1.3 | 13.1 | 1.9 | 7.5 |
| | 21 days | 5.0 | 16.3 | 3.1 | 20.3 |
| LSD | | 3.65 | 5.66 | 3.65 | 5.66 |

**Table 10. Effect of harvest date, delay in sealing CA containers, store oxygen concentration and storage duration on the severity (max. 60) of core flush in Braeburn apples subjected to 7 days at 20°C after storage. Data are mean values for fruit subjected to four different rates of establishment of CA conditions (see text).**

| | | Core flush (severity index max. 60) | | | |
|---|---|---|---|---|---|
| | | 2% $O_2$ | | 1.2% $O_2$ | |
| | | January | April | January | April |
| 4.10.07 | 0 days | 0.6 | 4.3 | 0.4 | 3.6 |
| | 21 days | 1.3 | 7.6 | 0.4 | 7.2 |
| 10.10.07 | 0 days | 0.3 | 2.6 | 0.4 | 1.5 |
| | 21 days | 1.0 | 3.4 | 0.6 | 4.2 |
| LSD | | 0.73 | 1.26 | 0.73 | 1.26 |

***Greasiness***

None of the apples were considered greasy either in January or April even when subjected to a 7 day period at 20°C. However, some of the fruits felt slightly sticky and an assessment was made of the 'feel' of the fruit. This was only carried out on fruit stored until January and subjected to a further 7 days at 20°C. Fruit from the second pick was stickier than that from the first pick. Storing in 1.2% $O_2$ as opposed to 2% $O_2$ reduced stickiness of fruit from the first pick only.

**Table 11. Effect of harvest date, delay in sealing CA containers and store oxygen concentration on the 'stickiness' of Braeburn subjected to 7 days at 20°C after storage. Data are mean values for fruit subjected to 4 different rates of establishment of CA conditions (see text).**

| | | Greasiness | | | |
|---|---|---|---|---|---|
| | | 2% $O_2$ | | 1.2% $O_2$ | |
| | | January | April | January | April |
| 4.10.07 | 0 days | 0.4 | - | 0.1 | - |
| | 21 days | 0.3 | - | 0.1 | - |
| 10.10.07 | 0 days | 0.5 | - | 0.5 | - |
| | 21 days | 0.5 | - | 0.4 | - |
| LSD | | 0.18 | - | 0.18 | - |

***Superficial scald and rotting***

None of the fruit was affected by superficial scald and there were only 7 rotted fruits out of 3840 fruits that were stored.

***Year 2***

***Fruit maturity***

In 2008 it was advised by the Quality Fruit Group that Braeburn destined for post-February storage should be completed in the period 10-17 October. This was based on data from marker sites that were compared with suggested starch values of 60-70% and 50-60% for storage to March and February respectively. At the first pick starch levels in fruit from the four orchards (74-85% black) slightly exceeded the suggested starch levels and at the second pick (58-70%) were generally within the recommended range for long-term storage. Fruit from the West Malling orchard (C) and Hernhill (D) orchards were similar in starch coverage and were lower in starch than those from Marden (T) or Upchurch (H). A delay in harvesting of two weeks resulted in an overall starch reduction of 16%.

**Table 12. Maturity parameters of Braeburn (Hillwell) apples sampled from four commercial orchards in 2008.**

| Orchard | Pick date | Mean Fruit Weight (g) | Firmness (kg) | Soluble solids (%) | Starch cover | |
|---|---|---|---|---|---|---|
| | | | | | Ctifl | % black |
| D | 10 Oct. | 156 | 98.9 | 13.1 | 5.3 | 74 |
| | 24 Oct. | 163 | 91.2 | 13.3 | 6.8 | 60 |
| | | | | | | |
| C | 10 Oct. | 135 | 94.7 | 11.2 | 5.0 | 77 |
| | 24 Oct. | 148 | 92.8 | 12.1 | 7.0 | 58 |
| | | | | | | |
| T | 10 Oct. | 145 | 99.8 | 12.9 | 3.9 | 85 |
| | 24 Oct. | 164 | 91.2 | 13.0 | 6.3 | 65 |
| | | | | | | |
| H | 10 Oct. | 146 | 94.8 | 12.3 | 4.5 | 81 |
| | 24 Oct. | 148 | 90.5 | 13.5 | 5.8 | 70 |
| | | | | | | |
| LSD | | | 3.22 | 0.36 | 1.06 | |

***Quality changes of stored fruit from early March to late April***

Levels of rotting were generally very low throughout storage (less than 1%) although a higher incidence was recorded in fruit stored until late April and subjected to a simulated marketing period. Background colour yellowed only slightly during the final 2 months of storage but firmness declined by 4.8 N (0.5kg).

The most significant change related to the development of core flush. The ex-store incidence of core flush virtually doubled in the final 2 months of storage. Subjecting fruits to a further 7 days at 20$^{o}$C increased core flush incidence by 77% (early March) and 50% (Late April). These data confirm the current recommendation to market Braeburn by March.

Brownheart (internal $CO_2$ injury) remained at a very low level (less than 0.5%) and was unaffected by storage duration. However flesh breakdown was more problematic in late-stored fruit particularly after a simulated marketing period. A low incidence of scald (1.8%) was recorded in fruit stored until late April and subjected to a simulated marketing period.

The challenges for extending the storage life of Braeburn are clear from these data. The impact of the pre- (orchards / harvest date) and post-harvest factors (delay in sealing stores / CA establishment rates / store oxygen concentration) on quality changes are considered in the remainder of the report.

**Table 13. The effect of storage duration on the quality of Braeburn apples. Data are mean values for fruit from 4 orchards picked on two occasions subjected to three different rates of establishment of CA conditions and stored in two low oxygen regimes (see text).**

| | Early March | | Late April | |
|---|---|---|---|---|
| | Ex-CA | +7 days at 20°C | Ex-CA | +7 days at 20°C |
| Wt. Loss (%) | 0.9 | - | 1.2 | - |
| Rots (%) | 0.4 | 0.7 | 0.8 | 2.8 |
| Background colour (1, green – 4, yellow) | 2.3 | - | 2.5 | - |
| Firmness (N) | 81.6 | - | 76.8 | - |
| Core Flush (%) | 11.1 | 19.7 | 21.5 | 32.3 |
| Core Flush severity (max 60) | 2.4 | 4.9 | 5.4 | 8.4 |
| Brownheart (%) | 0.3 | 0.3 | 0.3 | 0.4 |
| Flesh breakdown (%) | 0.1 | 1.9 | 2.7 | 7.6 |
| Flesh breakdown severity (max 60) | 0.01 | 0.38 | 0.72 | 2.05 |
| Scald (%) | 0 | 0 | 0 | 1.8 |

1 not measured.

***Effects of orchard site and picking date on Braeburn fruit quality***

There were marked effects of orchard site on fruit quality and on susceptibility of fruits to physiological disorders. In early March the core flush incidence in fruit from the worst-affected orchard (T) was 11-fold higher than those from the least affected orchard (H) (Table 14) and in late April there was a 6-fold difference (Table 15). The lack of consistent significant effects of harvest date on core flush development suggest that orchard effects on core flush incidence and severity are largely independent of any differences in harvest maturity. However, there were significant interactions between orchards and harvest date (see below).

The overall effect of delayed harvest was to reduce weight loss, increase yellowness of the background colour and to reduce firmness. The magnitude of the effect of delayed harvest varied among orchards. There was no overall effect of picking date on the development of physiological disorders in fruit stored until early March but there were

significant interactions between harvest date and orchards. There were significant effects of harvest date on the incidence and severity of core flush and flesh breakdown in fruit stored until late April although again there were significant interactions between harvest date and orchards. In fruit examined immediately ex-CA delayed harvest increased core flush incidence in fruit from orchard T only. The severity of core flush was significantly worse in the second pick of fruit from orchards C, T and H but was less in fruit from orchard D. There was a similar pattern of effects in fruit examined after a simulated marketing period with more core flush in the second pick of fruits from orchards C and T but less in the second pick of fruits from orchard D. Delayed harvest increased flesh breakdown in fruit from orchard C only.

It was interesting to note that the harvest starch levels in fruit worst affected by core flush (T) were similar to those in fruit from the least affected orchard (H). The incidence of brownheart was too low to justify a statistical analysis but it was interesting to note that brownheart affected fruit from only two orchards (C and T). Fruits that developed least core flush (orchards D and H) were free of brownheart and least affected by flesh breakdown.

Although with the exception of brownheart the incidence of physiological disorders increased during a simulated marketing period there was again no effect of harvest date but the marked effect of orchard site was again evident. The order in severity of core flush (least to worst – H, D, C and T) was the same as in fruit examined immediately ex-store and the same order generally applied to brownheart and flesh breakdown.

**Table 14. Effects of picking date (pick 1, 10.10.08 and pick 2, 24.10.08) and orchard site (Reference D, C, T and H) on the storage quality of Braeburn apples. Data are mean values for fruit subjected to three different rates of establishment of CA conditions and stored in two low oxygen regimes (see text) until early March 2009. Treatments effects were non-significant (n.s.) or significant at the 5% (*), 1% (**) or 0.1% (***) level.**

| Early March | Pick | | | Orchard | | | | |
|---|---|---|---|---|---|---|---|---|
| Ex-store | 1 | 2 | Sig. | D | C | T | H | Sig. |
| Wt. loss (%) | 1.05 | 0.71 | *** | 0.77 | 1.05 | 1.02 | 0.68 | *** |
| Background colour (1, green – 4, yellow) | 2.12 | 2.54 | *** | 2.59 | 2.19 | 2.40 | 2.13 | *** |
| Firmness (N) | 85.1 | 78.0 | *** | 81.5 | 84.4 | 80.6 | 79.8 | *** |
| Core Flush (%) | 10.3 | 11.7 | n.s. | 5.2 | 12.2 | 24.3 | 2.2 | *** |
| Core Flush severity (max 60) | 2.31 | 2.46 | n.s. | 1.09 | 2.54 | 5.46 | 0.46 | *** |
| Brownheart (%) | 0.31 | 0.20 | - | 0 | 0.20 | 0.83 | 0 | - |
| Flesh breakdown (%) | 0 | 0.10 | - | 0 | 0.20 | 0 | 0 | - |
| Flesh breakdown severity (max 60) | 0 | 0.02 | - | 0 | 0.04 | 0 | 0 | - |
| | | | | | | | | |
| Ex- 7days at 20$^{o}$C | | | | | | | | |
| Core Flush (%) | 20.3 | 19.1 | n.s. | 12.2 | 24.8 | 37.0 | 4.8 | *** |
| Core Flush severity (max 60) | 5.12 | 4.68 | n.s. | 2.75 | 6.05 | 9.70 | 1.09 | *** |
| Brownheart (%) | 0.31 | 0.31 | - | 0 | 0.42 | 0.83 | 0 | - |
| Flesh breakdown (%) | 1.67 | 2.08 | n.s. | 1.25 | 2.50 | 3.33 | 0.42 | ** |
| Flesh breakdown severity (max 60) | 0.35 | 0.41 | n.s. | 0.25 | 0.54 | 0.66 | 0.08 | ** |

- insufficient data to justify a statistical analysis

**Table 15. Effects of picking date (pick 1, 10.10.08 and pick 2, 24.10.08) and orchard site (Reference D, C, T and H) on the storage quality of Braeburn apples. Data are mean values for fruit subjected to three different rates of establishment of CA conditions and stored in two low oxygen regimes (see text) until late April 2009. Treatments effects were non-significant (n.s.) or significant at the 5% (*), 1% (**) or 0.1% (***) level.**

| Late April | Pick | | | Orchard | | | | |
|---|---|---|---|---|---|---|---|---|
| Ex-store | 1 | 2 | Sig. | D | C | T | H | Sig. |
| Wt. loss (%) | 1.41 | 0.91 | *** | 1.07 | 1.44 | 1.24 | 0.91 | *** |
| Background colour (1, green – 4, yellow) | 2.29 | 2.63 | *** | 2.71 | 2.30 | 2.59 | 2.22 | *** |
| Firmness (N) | 80.4 | 73.1 | *** | 76.5 | 80.9 | 74.0 | 75.5 | *** |
| Core Flush (%) | 20.0 | 22.9 | n.s. | 10.5 | 30.9 | 38.2 | 6.3 | *** |
| Core Flush severity (max 60) | 4.91 | 5.82 | * | 2.35 | 8.08 | 9.67 | 1.35 | *** |
| Brownheart (%) | 0.10 | 0.42 | - | 0 | 0.63 | 0.42 | 0 | - |
| Flesh breakdown (%) | 0.98 | 4.39 | *** | 1.88 | 5.72 | 2.31 | 0.83 | *** |
| Flesh breakdown severity (max 60) | 0.24 | 1.19 | *** | 0.42 | 1.61 | 0.68 | 0.17 | *** |
| | | | | | | | | |
| Ex- 7days at 20°C | | | | | | | | |
| Core Flush (%) | 27.4 | 37.0 | *** | 21.4 | 45.4 | 50.0 | 12.1 | *** |
| Core Flush severity (max 60) | 7.27 | 9.52 | *** | 5.46 | 12.50 | 13.12 | 2.50 | *** |
| Brownheart (%) | 0.42 | 0.42 | - | 0 | 0.63 | 1.04 | 0 | - |
| Flesh breakdown (%) | 6.25 | 8.96 | * | 5.83 | 15.62 | 7.50 | 1.46 | *** |
| Flesh breakdown severity (max 60) | 1.69 | 2.42 | * | 1.79 | 4.12 | 2.00 | 0.29 | *** |
| Scald (%) | 2.08 | 1.46 | n.s. | 1.04 | 4.38 | 1.67 | 0 | *** |

- insufficient data to justify a statistical analysis

*Effects of delay in sealing stores, rate of CA establishment and store oxygen concentration on Braeburn fruit quality*

Storing in 1.2% oxygen resulted in a consistently lower weight loss compared with the higher oxygen level (2%) (Table 16). The lower weight loss in 1.2% oxygen can be attributed to an expected reduced respiration which would reduce dry matter loss directly

and water loss due to less container ventilation. The effects of delay and time to CA were inconsistent.

**Table 16. Effect of delay in sealing CA containers, rate of CA establishment and store oxygen concentration on weight loss (%) in Braeburn apples. Data are mean values for fruit from 4 orchards picked on 2 occasions (see text).**

| | Weight loss (%) | | | | | |
|---|---|---|---|---|---|---|
| | Time to achieve CA | | | | | |
| | Immediate | | 7 days | | 14 days | |
| Delay in sealing stores | Store oxygen concentration | | | | | |
| Early March | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ |
| 0 days | 1.1 | 0.6 | 1.3 | 0.6 | 0.9 | 0.6 |
| 21 days | 0.8 | 0.7 | 1.2 | 0.8 | 1.2 | 0.7 |
| LSD = 0.09 | | | | | | |
| Late April | | | | | | |
| 0 days | 1.6 | 0.7 | 1.3 | 0.8 | 1.3 | 0.8 |
| 21 days | 1.0 | 0.8 | 1.9 | 1.0 | 1.7 | 1.0 |
| LSD = 0.18 | | | | | | |

Retention of a green background colour was achieved by immediate sealing of storage containers, quicker establishment of CA conditions and maintaining storage oxygen at 1.2% as opposed to 2% (Table 17).

Store oxygen concentration was the largest effect followed by delay in sealing and finally rate of CA establishment. Although the treatment effects were statistically significant the practical differences were slight when compared effects of orchards and pick date.

**Table 17. Effect of delay in sealing CA containers, rate of CA establishment and store oxygen concentration on the background colour of Braeburn apples. Data are mean values for fruit from 4 orchards picked on 2 occasions (see text).**

| | Ground colour (1, green – 4, yellow) | | | | | |
|---|---|---|---|---|---|---|
| | Time to achieve CA | | | | | |
| Early March | Immediate | | 7 days | | 14 days | |
| Delay in sealing stores | Store oxygen concentration | | | | | |
| | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ |
| 0 days | 2.4 | 2.3 | 2.4 | 2.3 | 2.3 | 2.2 |
| 21 days | 2.4 | 2.4 | 2.4 | 2.3 | 2.4 | 2.3 |
| LSD = 0.10 | | | | | | |
| Late April | | | | | | |
| 0 days | 2.5 | 2.4 | 2.5 | 2.4 | 2.4 | 2.4 |
| 21 days | 2.5 | 2.5 | 2.5 | 2.5 | 2.6 | 2.6 |
| LSD = 0.08 | | | | | | |

Effects of storage treatments on fruit firmness were similar to those described for background colour. However delay in sealing the storage containers had the greatest adverse effect on firmness followed by the higher level of oxygen and to a far lesser extent a slower rate of CA establishment (Table 18).

The difference in firmness between the optimal treatment combination (No delay, immediate CA and 1.2% oxygen) and least effective combination (21 days delay, 14 days establishment of CA and 2% oxygen) was 11 N (approximately 1 kg).

**Table 18. Effect of delay in sealing CA containers, rate of CA establishment and store oxygen concentration on the firmness (N) of Braeburn apples. Data are mean values for fruit from 4 orchards picked on 2 occasions (see text).**

| | Firmness (N) | | | | | |
|---|---|---|---|---|---|---|
| | Time to achieve CA | | | | | |
| | Immediate | | 7 days | | 14 days | |
| Delay in sealing stores | Store oxygen concentration | | | | | |
| Early March | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ |
| 0 days | 83.9 | 86.9 | 83.6 | 86.6 | 80.5 | 85.6 |
| 21 days | 78.5 | 79.5 | 78.7 | 80.1 | 75.9 | 79.5 |
| LSD = 1.42 | | | | | | |
| Late April | | | | | | |
| 0 days | 77.0 | 82.8 | 76.7 | 82.0 | 76.65 | 81.4 |
| 21 days | 71.5 | 75.7 | 74.6 | 76.4 | 72.2 | 74.4 |
| LSD = 1.63 | | | | | | |

In fruit removed from store in early March the incidence and severity of core flush was reduced by avoiding any delay in sealing the storage containers and by storing in 1.2% oxygen (Tables 19 and 20). Rate of CA establishment had no effect on core flush development. However, there was no effect of storage treatments on core flush in fruits examined after a simulated marketing period.

In fruit removed from store in late April less core flush was evident in fruit stored in the lower level of oxygen (1.2%) but there was little effect of delay in sealing stores or rate of CA establishment.

There was little effect of storage treatments on core flush development during simulated marketing period. It is clear that core flush potential of fruits is determined primarily by orchard site with some effect of harvest date in reducing core flush in fruit stored until late April and subjected to a simulated marketing period.

Although there may be some amelioration of core flush by modifying storage practice it is clear that some understanding of the pre-harvest factors that influence susceptibility to core flush is essential if storage of Braeburn to late April is to be assured.

**Table 19. Effect of delay in sealing CA containers, rate of CA establishment and store oxygen concentration on the incidence (%) of core flush in Braeburn apples. Data are mean values for fruit from 4 orchards picked on 2 occasions (see text).**

| | Core flush (%) | | | | | |
|---|---|---|---|---|---|---|
| | Time to achieve CA | | | | | |
| | Immediate | | 7 days | | 14 days | |
| Delay in sealing stores | Store oxygen concentration | | | | | |
| Early March | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ |
| 0 days | 6.3 | 3.1 | 13.1 | 4.4 | 13.8 | 3.8 |
| 21 days | 22.6 | 8.1 | 11.9 | 13.8 | 19.4 | 12.5 |
| LSD = 5.99 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 18.3 | 22.5 | 16.3 | 15.6 | 21.7 | 18.1 |
| 21 days | 19.4 | 21.3 | 25.6 | 13.8 | 23.1 | 21.3 |
| LSD = 6.95 | | | | | | |
| Late April | | | | | | |
| 0 days | 25.1 | 13.4 | 22.7 | 18.3 | 26.0 | 18.9 |
| 21 days | 25.6 | 22.5 | 22.4 | 15.3 | 24.1 | 23.8 |
| LSD = 7.58 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 28.1 | 28.1 | 31.9 | 27.5 | 28.1 | 40.0 |
| 21 days | 37.6 | 39.4 | 24.4 | 34.4 | 26.9 | 40.6 |
| LSD = 9.54 | | | | | | |

**Table 20. Effect of delay in sealing CA containers, rate of CA establishment and store oxygen concentration on the severity of core flush in Braeburn apples. Data are mean values for fruit from 4 orchards picked on 2 occasions (see text).**

| | Core flush severity index (max 60) | | | | | |
|---|---|---|---|---|---|---|
| | Time to achieve CA | | | | | |
| | Immediate | | 7 days | | 14 days | |
| Delay in sealing stores | Store oxygen concentration | | | | | |
| Early March | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ |
| 0 days | 1.3 | 0.6 | 2.6 | 0.9 | 2.8 | 0.8 |
| 21 days | 5.3 | 1.8 | 2.6 | 3.0 | 4.3 | 2.9 |
| LSD = 1.40 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 4.8 | 5.6 | 3.8 | 3.6 | 5.3 | 3.9 |
| 21 days | 5.4 | 5.9 | 6.9 | 2.8 | 6.3 | 4.6 |
| LSD = 1.86 | | | | | | |
| Late April | | | | | | |
| 0 days | 5.9 | 3.0 | 5.8 | 4.2 | 7.3 | 4.4 |
| 21 days | 6.4 | 5.5 | 5.2 | 3.7 | 6.3 | 6.6 |
| LSD = 2.22 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 7.5 | 7.5 | 7.6 | 7.1 | 8.5 | 10.4 |
| 21 days | 10.3 | 10.5 | 5.9 | 7.9 | 7.3 | 10.4 |
| LSD = 3.21 | | | | | | |

The average incidence of brownheart was very low (0.3%) and consequently statistical analysis was not appropriate. Brownheart is potentially very serious in Braeburn and current storage practice (21-day delay in sealing stores and use of modest (2%) concentrations of oxygen) recognises the potential of fruit to develop $CO_2$-related problems such as Braeburn Browning Disorder. Brownheart did not develop in fruits from orchards D and H regardless of storage treatments so for these orchards any potential quality benefits from more rapid attainment of storage conditions can be realised although further commercial trials are advised to ensure that fruits behave consistently despite variable growing conditions in different years. Data for fruit examined ex-CA and

ex-simulated marketing were combined (not presented) to give a more robust analysis. In general the results supported the view that more rapid establishment of conditions was more conducive to brownheart. Sealing of stores immediately after cooling followed by immediate establishment of low oxygen conditions by nitrogen injection produced most brownheart and would not be advised for commercial practice. In any of the other storage treatments brownheart tended to occur sporadically (Table 21).

**Table 21. Effect of delay in sealing CA containers, rate of CA establishment and store oxygen concentration on the incidence (%) of brownheart in Braeburn apples. Data are mean values for fruit from 4 orchards picked on 2 occasions (see text).**

| | Brownheart (%) | | | | | |
|---|---|---|---|---|---|---|
| | Time to achieve CA | | | | | |
| | Immediate | | 7 days | | 14 days | |
| Delay in sealing stores | Store oxygen concentration | | | | | |
| Early March | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ |
| 0 days | 1.9 | 0.6 | 0.6 | 0 | 0 | 0 |
| 21 days | 0 | 0 | 0 | 0 | 0 | 0 |
| LSD = 0.87 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 0 | 0.6 | 0.6 | 0 | 0.6 | 1.3 |
| 21 days | 0 | 0.6 | 0 | 0 | 0 | 0 |
| LSD = 1.24 | | | | | | |
| Late April | | | | | | |
| 0 days | 0.6 | 0.6 | 0 | 0.6 | 0 | 0.6 |
| 21 days | 0 | 0 | 0 | 0 | 0 | 0.6 |
| LSD = 1.13 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 0 | 1.9 | 0 | 1.3 | 0 | 0 |
| 21 days | 1.3 | 0 | 0.6 | 0 | 0 | 0 |
| LSD = 1.60 | | | | | | |

Increasing the length of storage enhanced the development of flesh breakdown. Clearly this problem, along with that caused by core flush development, needs to be resolved if English Braeburn is to be stored into April. Flesh breakdown increased during a simulated marketing period (Tables 22 and 23).

It is necessary to ensure that fruit is marketed promptly when fruit is removed from commercial CA stores and that cool temperatures are during distribution and marketing wherever possible. Adopting these practices is also likely to minimise core flush development.

In fruit examined immediately ex-CA storage in late April a higher incidence of flesh breakdown was recorded where sealing of storage containers was delayed by 21 days and where CA conditions were established slowly but there was no significant effect of store oxygen. However, treatment differences apparent immediately ex-CA were not evident in samples kept in simulated marketing conditions.

**Table 22. Effect of delay in sealing CA containers, rate of CA establishment and store oxygen concentration on the incidence of flesh breakdown in Braeburn apples. Data are mean values for fruit from 4 orchards picked on 2 occasions (see text).**

| | Flesh breakdown (%) | | | | | |
|---|---|---|---|---|---|---|
| | Time to achieve CA | | | | | |
| | Immediate | | 7 days | | 14 days | |
| Delay in sealing stores | Store oxygen concentration | | | | | |
| Early March | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ |
| 0 days | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 days | 0 | 0 | 0 | 0 | 0.6 | 0 |
| LSD = 0.50 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 0.6 | 3.1 | 0 | 0.6 | 1.3 | 1.3 |
| 21 days | 2.5 | 3.1 | 5.0 | 0.6 | 2.5 | 1.9 |
| LSD = 3.12 | | | | | | |
| Late April | | | | | | |
| 0 days | 2.5 | 1.3 | 0.6 | 2.6 | 2.0 | 2.5 |
| 21 days | 1.3 | 2.5 | 1.3 | 4.4 | 6.3 | 5.0 |
| LSD = 3.53 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 6.3 | 7.5 | 5.6 | 7.5 | 9.4 | 7.5 |
| 21 days | 10.6 | 9.4 | 3.8 | 9.4 | 4.4 | 10.0 |
| LSD = 5.81 | | | | | | |

**Table 23. Effect of delay in sealing CA containers, rate of CA establishment and store oxygen concentration on the severity of flesh breakdown in Braeburn apples. Data are mean values for fruit from 4 orchards picked on 2 occasions (see text).**

| | Flesh breakdown severity index (max. 60) | | | | | |
|---|---|---|---|---|---|---|
| | Time to achieve CA | | | | | |
| | Immediate | | 7 days | | 14 days | |
| Delay in sealing stores | Store oxygen concentration | | | | | |
| Early March | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ |
| 0 days | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 days | 0 | 0 | 0 | 0 | 0.1 | 0 |
| LSD = 0.10 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 0.1 | 0.6 | 0 | 0.1 | 0.3 | 0.3 |
| 21 days | 0.5 | 0.8 | 1.0 | 0.1 | 0.5 | 0.4 |
| LSD = 0.67 | | | | | | |
| Late April | | | | | | |
| 0 days | 0.6 | 0.3 | 0.1 | 0.8 | 0.7 | 0.5 |
| 21 days | 0.5 | 0.6 | 0.4 | 1.0 | 1.8 | 1.4 |
| LSD = 1.01 | | | | | | |
| 7 days at 20°C | | | | | | |
| 0 days | 1.6 | 2.0 | 1.8 | 2.1 | 2.1 | 2.3 |
| 21 days | 3.0 | 2.5 | 1.0 | 2.5 | 1.3 | 2.5 |
| LSD = 1.79 | | | | | | |

A low incidence of scald was recorded on fruit from 3 orchards stored until late April and subjected to a further 7 days at 20°C. Scald development was restricted to fruit stored in the higher concentration (2%) of oxygen (Table 24).

**Table 24. Effect of delay in sealing CA containers, rate of CA establishment and store oxygen concentration on the incidence (%) of scald in Braeburn apples. Data are mean values for fruit from 4 orchards picked on 2 occasions (see text).**

| | Scald (%) | | | | | |
|---|---|---|---|---|---|---|
| | Time to achieve CA | | | | | |
| | Immediate | | 7 days | | 14 days | |
| Delay in sealing stores | Store oxygen concentration | | | | | |
| Late April | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ | 2% $O_2$ | 1.2% $O_2$ |
| 7 days at 20°C | | | | | | |
| 0 days | 3.8 | 0 | 2.5 | 0 | 0 | 0 |
| 21 days | 3.8 | 0 | 7.5 | 0 | 3.8 | 0 |
| LSD = 3.72 | | | | | | |

**Discussion**

The current recommendation to wait for 21 days before sealing CA stores of Braeburn is based on international experience and is intended to prevent CA injury problems such as Braeburn Browning Disorder (BBD). The current HDC storage recommendations wall chart refers to the Best Practice Guide for UK apples which stipulates the 21-day delay. It was expected that there would be significant benefits in achieving CA conditions more rapidly and by maintaining lower concentrations of oxygen during the storage period. This is consistent with general storage advice provided in the UK Best Practice Guide for UK Apple Production (2001) (currently under revision by the HDC).

In both years of the project the sealing of storage containers immediately after cooling as opposed to a delay of 21 days (currently recommended and based on a perceived risk of $CO_2$-related problems such as Braeburn Browning Disorder and brownheart) conferred advantages for fruit quality. Firmness and green background colour was maintained more effectively by sealing the storage containers immediately after cooling as opposed to delaying sealing by 21 days. The subsequent rate of establishing CA conditions (0, 7, 10 and 14 days in 2007 and 0, 7 and 14 days in 2008) had little or no effects on retention of greenness or firmness but storing in 1.2% $O_2$ as opposed to 2% $O_2$ provided greener, firmer fruit in both years.

Although it is important to maximise the visual and eating quality of Braeburn throughout storage the current limitations in storage life relate primarily to the development of physiological disorders such as core flush and flesh breakdown. The 2008 experiment showed clearly the increased development of disorders in the final two months of storage. From early March to late April the incidence of core flush virtually doubled, flesh breakdown was more problematic and a low incidence of scald was recorded in fruit stored until late April and subjected to a simulated marketing period.

The main focus of the project is to assess the prospect for amelioration of these disorders through modification of storage practice. The results of work done in Year 1 of the project were very encouraging. In fruit from a single orchard a 3-fold reduction in core flush incidence was achieved by sealing stores immediately after cooling as opposed to a delay of 21 days. In Year 2 immediate sealing of storage containers resulted in a 2-fold reduction in core flush incidence in fruit removed from store in March but the effect was lost when storage was extended to late April and when fruit was kept in simulated marketing conditions. However, immediate sealing was beneficial in terms of reducing flesh breakdown in fruit stored until April.

Although it was anticipated that that a more rapid rate of establishing CA conditions might be beneficial to retention of green colour and firmness this was not the case in the 2007 experiment and there were only slight benefits on these quality parameters in the 2008 experiment. More rapid establishment offered no advantage in terms of reducing the development of disorders.

Maintaining store oxygen concentrations at 1.2% as opposed to the currently recommended 2% was advantageous. Fruit stored in the lower oxygen regime lost less weight, retained a greener background colour and higher firmness and developed less core flush. The low incidence of scald that developed in fruit stored until late April and subjected to a further 7 days at 20$^{o}$C was restricted to fruit in the higher (2%) concentration of oxygen.

Although changes in store management resulted in some positive effects on fruit quality these were often slight when compared with the marked influence of orchard site. It is clear that to extend the storage of Braeburn to late April or early May growers need to be

aware of the storage behaviour of fruits from their orchards and to accumulate data over a number of seasons. There is no knowledge of site factors that influence susceptibility of fruits to core flush and results from this and a previous project suggest no consistent effect of harvest date. Further research would be required to study the effects of pre-harvest (orchard and climatic) factors on susceptibility of Braeburn to core flush and flesh breakdown.

In this study there was no attempt to study effects of clones on storage quality. The Hillwell clone was chosen since this seems to be the one favoured by English growers. In previous HDC-funded work (TF 152) Lochbuie was more affected by core flush than Hillwell or Schneider.

**Conclusions**

- On the basis of the results obtained in the two years of the project it is clear that changes in store management could be advocated that would be benefit the quality of fruit and increase the possibility of extending the storage period beyond early March.
- In particular it is clear that advantages accrue from sealing stores immediately after the fruit has cooled to final holding temperature (1.5-2$^{o}$C) and from storing in 1.2% oxygen rather 2%.
- However, there remains a concern that implementing a more stringent store management regime may induce brownheart (internal $CO_2$) in the fruit.
- Despite no brownheart occurring in the 2007 experiment and only to a very slight extent in 2 of the 4 orchards studied in the 2008 experiment it is advised that growers carry out further testing of this modified storage protocol before it is implemented on a wider scale.
- It is imperative that only fruit of an appropriate maturity for long-term storage is subjected to this revised protocol.
- Late picked fruit are likely to respond adversely and may develop $CO_2$-related injuries.
- The results of this project relate only to the Hillwell clone of Braeburn and to the specified harvest maturity of fruits.

- Where storage beyond early March is not a requirement for particular growers then current storage protocols (delayed sealing of stores by 21 days and storage in 2% oxygen) is advised particular when fruit is picked later than recommended.

**Technology transfer**

HDC News (submitted June 2009).

**Glossary**

**References**

Defra Best Practice Guide for UK Apple Production (2001). Currently under revision by HDC.

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