Project Title:	Storage of Braeburn apples
Project Number:	TF152
Report:	Final Report
Previous reports:	Year 1 Report July 2004 Year 2 Report July 2005
Project consultant:	None
Key Workers:	Mr David Johnson, East Malling Research Dr Martin Luton, Worldwide Fruit/Qualytech Mr Andrew Russell, Worldwide Fruit/Qualytech Mr Tim Biddlecombe, FAST Ltd
Location of Project:	East Malling Research New Road East Malling Kent ME19 6BJ Tel: 01732 843833 Fax: 01732 849067
Project Co-ordinator:	Andrew Tinsley
Date Project commenced:	1 July 2003
Date Completion due:	30 June 2006
Keywords:	apple, storage, Braeburn, maturity, clones, CA

CONTENTS

Grower summary

Scientific section

East Malling Research

Principal Scientists and authors of report:

D S Johnson (Post-harvest physiologist and project leader)
Dr Martin Luton, Worldwide Fruit/Qualytech
Mr Andrew Russell, Worldwide Fruit/Qualytech
Mr Tim Biddlecombe, FAST Ltd

Authentication

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

....
D S Johnson
Signature

Date …………………………….......................................

Grower summary

TF 152

Storage of Braeburn apples

Final report to 30 June 2006

Grower summary

Headline

- Picking Braeburn at too immature a stage will result in an inferior appearance and eating quality, and a heightened susceptibility to superficial scald, but picking too late can result in a greasy skin and poor texture of the flesh.

- Air stored fruit should be kept at 0-0.5°C and storage terminated by December.

- CA stored fruit should be kept at <1% CO_2, 2% O_2 and at 1.5-2°C until late February - early March. This CA regime should be established 3 weeks after loading to avoid potential injury to the fruit.

Background and expected deliverables

The number of Braeburn orchards in the UK is increasing. Clones currently favoured by UK growers include Hillwell, Schneider and Lochbuie. As production increases there will be a need to provide growers with advice on when to harvest and on the most appropriate conditions for storage. No previous storage research has been carried out in the UK on this variety although prior to this project FAST Ltd and Worldwide Fruit (WWF) assessed harvest maturity in relation to eating quality of stored fruit on behalf of certain multiple retailers. Results of work done abroad suggest that storage could be problematic since the variety is susceptible to calcium-dependent disorders and is damaged by more stringent controlled atmosphere (CA) regimes. It is also susceptible to scald in long-term CA conditions. Advice provided in the *Defra Best Practice Guide for UK Apple Production* is based on Belgian experience.

The aim of this three-year project was to undertake detailed trials to establish the optimum maturity indices and storage conditions for Braeburn and its clones grown in the UK. The work was aimed at providing growers and marketers with (i) the maturity criteria for harvesting UK grown Braeburn apples intended for storage, (ii) recommendations for the short- and long-term storage of Braeburn apples and (iii) information on the clonal differences in harvest maturity and storage potential.

Summary of project and main conclusions

Braeburn apples from six commercial orchards were used in the study. There were two orchards for each of the three clones (Hillwell, Lochbuie and Schneider) currently favoured by UK growers. Samples of fruit for maturity assessment and storage tests were picked on six occasions at weekly intervals beginning on 25 September 2003 and on four occasions at weekly intervals beginning on 1 October 2004 and 3 October 2005.

In 2003 and 2004, fruit was stored in air and controlled atmosphere (CA) conditions (2% O_2, <1% CO_2) at 0-0.5°C and 1.5-2°C. In 2005, only one temperature was used for air (0-0.5°C) and CA-stored (1.5-2°C) fruit. Establishment of CA conditions was delayed for 21 days to reduce susceptibility to Braeburn Browning Disorder (BBD). After the 21-day delay, low oxygen CA conditions were established by flushing the storage containers with nitrogen. In 2005, only additional fruit was taken from picks 2 and 3 (10 and 17 October) in order to compare the quality of fruit stored in 2% with that in 1.2% O_2 (<1% CO_2) and to compare the effects of normal (sealed after cooling and CA achieved within 14 days) and delayed (sealed 3 weeks from loading and nitrogen flushed) establishment of CA conditions (2% O_2, <1% CO_2).

Measurements on samples taken at harvest for maturity assessment included internal ethylene concentration (IEC), background colour, firmness, soluble solids concentration and starch staining pattern. Samples of apples from each harvest were removed from air storage in late November/early December and in late January, and from CA storage in late January/early February and late April.

After weighing, one set of samples was used for an immediate assessment of quality (background colour, firmness and soluble solids concentration) and a similar set of samples was transferred to containers in air at 20°C. Samples previously stored at 1.5-2°C were removed after 4 days and a few apples were used for sensory evaluation by representatives of WWF, FAST Ltd and EMR. The remainder of the samples were placed back into 20°C. Samples previously stored at both temperatures were removed after 7 days at 20°C for an assessment of external and internal condition.

Air storage

For storage in air until late November/early December, there were no constraints imposed by the development of disorders. Consequently, picking date could be directed to achieving the desired appearance, optimum eating quality and least greasiness of the skin.

For storage in air until late January, core flush and scald development were major and minor constraints respectively. Although scald could be avoided by later picking, it was not possible to avoid core flush by modifying harvest date or storage temperature. Late January was not achievable in air storage in any of the years. The termination month for air storage should be December and for longer term storage CA must be used.

Fruit benefited from the lower storage temperature particularly as regards reduced weight loss and higher firmness and the recommended storage (fruit) temperature is 0-0.5°C.

CA storage

Generally, for storage in CA until late January/early February, there was little constraint imposed by the development of disorders, although in 2004 core flush developed to a slight extent (3.7%) in fruit removed from store in January and subjected to ‘shelf-life’ conditions. Consequently, consideration of optimum harvest dates and storage temperatures for CA storage until late January was mainly concerned with physical and sensory assessments of quality.

Late April was not achievable in CA storage in any of the years of the study. Major constraints were scald, core flush and internal breakdown. In some seasons core flush was also evident in commercial fruit marketed late in the season. In some years late picking and storage at low temperature (0-0.5°C) increased core flush but the problem could not be ameliorated by earlier harvesting and storing at higher temperatures.

It is difficult to set a termination month for CA-stored Braeburn, as susceptibility to physiological disorders varies significantly from season to season. Suggested termination months are late February/early March, which is earlier than commercially desirable. Fruit should be stored in 2% O_2, <1% CO_2 at 1.5-2°C and the quality of fruit in store should be monitored carefully and regularly in order to detect the first signs of core flush development. It is particularly important to subject fruit samples to 7 days at 20°C to simulate ‘shelf-life’ and to achieve an early warning of core flush development in fruit in the store.

Effect of store oxygen concentration and rate of establishment of CA conditions

In 2005, storing Braeburn apples (picks 2 and 3 only) in 1.2% O_2 as opposed to 2% O_2 (both conditions established by nitrogen flushing three weeks from harvest/loading) resulted in slightly greener fruit ex-store, but had no other significant effects on storage quality. Similarly, establishing CA conditions slowly by fruit respiration over 14 days or by nitrogen flushing after 21 days provided similar quality of fruit ex-store. Average levels of rotting were low in fruit from all treatments even after 7 days at 20°C (0.7% in January and 1.6% in April), but least rotting occurred in fruit stored in 2% O_2 and subjected to a three-week delay in CA establishment.

Preliminary results suggest that it may be safe to seal stores once the fruit has reached the holding temperature (1.5-2°C) and that 1.2% may be used instead of 2% O_2. However, with only one year of data limited to fruit from only two harvest dates, it is not advised that growers deviate from the recommendation to use 2% O_2 and to establish after a three-week delay. Clearly, Braeburn suffers no adverse effect of rapid establishment of CA by nitrogen flushing after a three week delay. Without nitrogen flushing stores can be sealed sooner than three weeks and further work is required to define establishment parameters and minimum store oxygen concentrations.

Harvest maturity

Based on data obtained in all years of the study, the picking ‘window’ is quite narrow for Braeburn. The following criteria were used to identify the optimum harvest date:

- Avoidance of scald
- Background colour maximum score of 2 (light green) on WWF colour chart
- Firmness minimum of 6.8 kg at despatch
- Greasiness maximum score of 1 on 0-5 scale

It was reassuring that during the three years of the trial the starch iodine test could be used to indicate optimum time of harvest. Firmness was too variable between the years to be of use as a guide to harvest date and there was little change in soluble solids concentrations over the harvesting period. Starch levels suggested for optimum storage quality are as follows:

	Starch	
	% surface black	**Ctifl 1-black, 10-white**
Air storage December	85-75	3-5
CA storage January	85-75	3-5
CA storage March	80*-75	4*-5

* Lower starch coverage required to reduce risk of superficial scald

Picking according to these starch criteria generally provided the best eating quality in each of the years.

Picking earlier than indicated by starch levels is likely to lead to poor appearance, loss of eating quality and wastage due to scald development. Later harvesting will lead to greasiness, loss of appearance and eating quality and is only appropriate for shorter term storage.

Clonal differences

Orchards of all three clones were present on one of the farms used in the study, but the remaining three orchards were on different farms and, as a consequence, any potential clonal differences were likely to be confounded by effects of orchard location.

None of the clones tested scored highest for all aspects of storage. Although Lochbuie was consistently the firmest clone and often least greasy, it lost the most weight and developed most core flush in CA storage. The information provided to growers on harvest maturity parameters and storage conditions are considered relevant to all clones tested.

Financial benefits

Optimum quality of fruit from store is essential in order to achieve the best financial returns. The project has established guidelines on when to harvest Braeburn and has determined the best conditions of storage and has set termination dates to avoid wastage and loss of quality. Growers adhering to the information provided below (see action points) should derive maximum financial benefit from their crops.

Action points

- Growers need to be aware of advice being provided on the best time to harvest Braeburn. This will be available through the Quality Fruit Group (QFG) and other sources.

- Maturity criteria for picking for storage are: starch cover of 85-75 (% black) for air storage until December and CA storage until January. Contrary to common practice, fruit intended for long-term (March) CA storage should be harvested slightly more mature, starch cover of 80-75%, in order to reduce the risk of superficial scald. Picking at the higher end of these ranges for starch is likely to provide the longest storage potential.

- Picking Braeburn at too immature a stage will result in an inferior appearance and eating quality and a heightened susceptibility to superficial scald.

- Picking too late can result in a greasy skin and poor texture of the flesh.

- The storage temperature for air and CA-stored fruit should be 0-0.5°C and 1.5-2°C respectively.

- The most appropriate CA regime comprises <1% CO_2, 2% O_2 and should be established three weeks after loading to avoid potential injury to the fruit. Where possible, nitrogen flushing should be used to establish low oxygen conditions following the three-week delay. Refer also to the Best Practice Guide for UK Apple Production for further advice on storage recommendations.

- Avoid storing too long. Provisional termination months for air and CA-stored fruit are December and late February - early March respectively. The development of scald or core flush will determine the duration of storage that is possible in any particular year.

- Monitor fruit condition regularly and include a simulated marketing test in order to detect the first signs of scald and core flush development. Refer also to the Best

Practice Guide for UK Apple Production for further advice on monitoring the condition of fruit in store.

Science Section

Introduction

The number of Braeburn orchards in the UK is increasing. Clones currently favoured by UK growers include Hillwell, Schneider and Lochbuie. As production increases there will be a need to provide growers with advice on when to harvest and on the most appropriate conditions for storage. No previous storage research has been carried out in the UK on this variety although, in the two years prior to the start of this project, FAST Ltd and Worldwide Fruit (WWF) assessed harvest maturity in relation to eating quality of stored fruit on behalf of certain multiple retailers. Results of work done abroad suggest that storage could be problematic since the variety is susceptible to calcium-dependent disorders and is damaged by more stringent controlled atmosphere (CA) regimes. It is also susceptible to scald in long-term CA conditions. Advice provided in the *Defra Best Practice Guide for UK Apple Production* is based on Belgian experience.

Aims of the project

The aim of this three-year project is to undertake detailed trials to establish the optimum maturity indices and storage conditions for Braeburn and its clones, grown in the UK. The work will provide growers and marketers with (i) the maturity criteria for harvesting UK grown Braeburn apples intended for storage, (ii) recommendations for the short- and long-term storage of Braeburn apples and (iii) information on the clonal differences in harvest maturity and storage potential.

Outline of results from year 1

Braeburn apples from six commercial orchards in Kent were used in the study. There were two orchards for each of the three clones (Hillwell, Lochbuie and Schneider) currently favoured by UK growers. Orchards of all three clones were present on one of the farms used in the study but the remaining three orchards were on different farms and as a consequence any potential clonal differences were likely to be confounded by effects of orchard location.

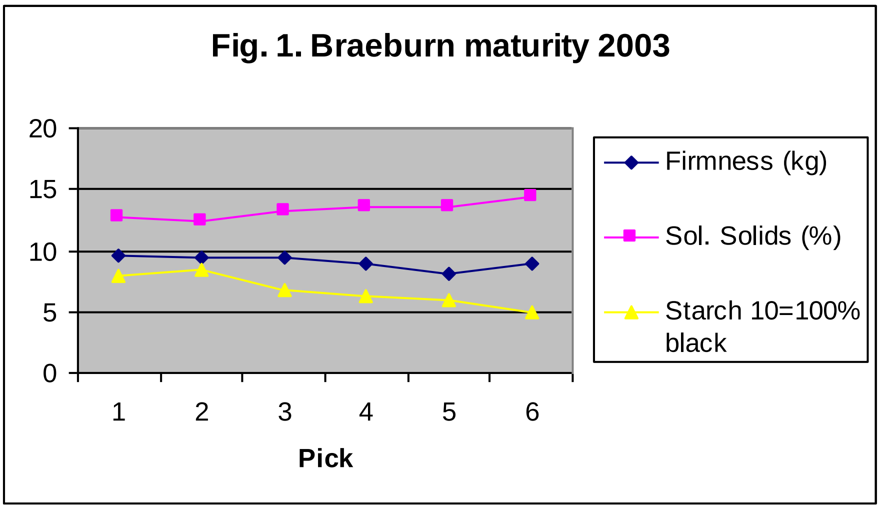
Samples of fruit for maturity assessment and storage tests were picked on six occasions at weekly intervals beginning on 25 September 2003. Fruits were selected at random from trees reserved for the study and apart from the first pick only fruit above 65 mm were sampled. After picking, all fruit was transported immediately to the Jim Mount Building at EMR.

Fruit was selected at random from the crop from each orchard to form 20-fruit samples for maturity assessment and for storage in air and controlled atmosphere (CA) conditions (2% O_2, <1% CO_2) at 0-0.5^{o}C and 1.5-2^{o}C. Storage samples were placed into 360 L containers on the same day as picking, but establishment of CA conditions was delayed for 21 days to reduce susceptibility to Braeburn Browning Disorder (BBD). CA conditions were established by flushing the containers with nitrogen and CO_2 produced by fruit respiration was removed continuously using hydrated lime scrubbers. Oxygen concentrations were maintained at 2% by automated injection of compressed air. Gas measurement and control was achieved using an ICA 66 system (International Controlled Atmosphere Ltd).

Measurements on samples taken at harvest for maturity assessment included internal ethylene concentration (IEC), background colour, firmness, soluble solids concentration and starch staining pattern. Assessment methods were similar to those described for year 3 of the project (see page 20). Work was carried out in accordance with HRI experimental procedures and protocols. Smith (1985) has described many of the objective methods used for the assessments of quality in apples.

The Streif maturity index was calculated by dividing the firmness value expressed in Newtons (kg*9.81) by the product of the soluble solids concentration (%) and starch cover (%) subtracted from 100. Samples of apples from each harvest were removed from air storage on 24 November 2003 and 26 January 2004 and from CA storage on 2 February and 26 April 2004. After weighing, one set of samples were used for an immediate assessment of quality (background colour, firmness and soluble solids concentration) and a similar set of samples was transferred to containers in air at 20^{o}C. Samples previously stored at 1.5-2^{o}C were removed after 4 days and a few apples were used for sensory evaluation by representatives of WWF and EMR. The remainder of the samples were placed back into 20^{o}C. Samples previously stored at both temperatures were removed after 7 or 8 days at 20^{o}C for an assessment of external and internal condition. Each fruit was examined externally for the presence of rotting and external physiological disorders such as superficial scald. An assessment was made of the greasiness of the skin either ex-store or after 4 or 7 days at 20ºC. Finally all the fruits were cut and examined for internal physiological disorders.

Harvest Maturity



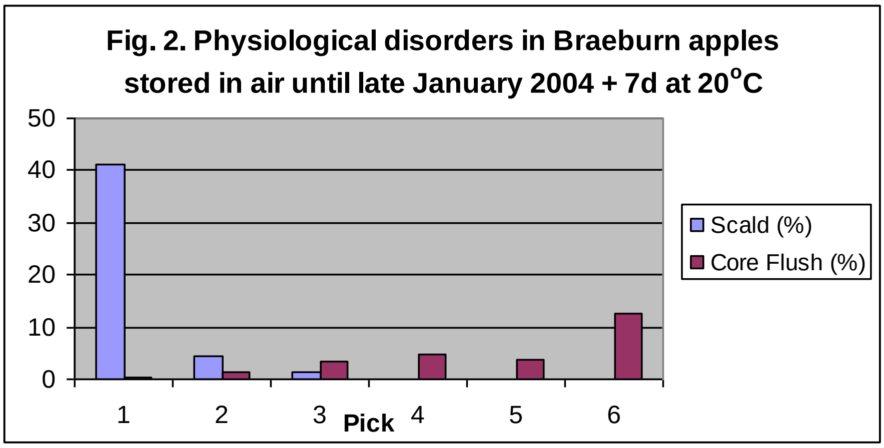
Delay in picking was associated with a progressive yellowing of the background colour (data not presented) and a progressive loss of firmness and starch (Figure 1). An unexpectedly high firmness reading was recorded at the final pick which in part may be due to the reduction in the number of orchards sampled from 6 to 4 which was due to insufficient trees being left after commercial picking. There was no significant change in the concentration of soluble solids over the 6 picks.

Air storage late November

For storage in air until late November there were no constraints imposed by the development of disorders. Consequently picking date could be directed to achieving the desired appearance, optimum eating quality and least greasiness of the skin. On the basis of appearance and eating quality pick 1 fruit (25 September) was clearly too immature. Greasiness was a problem in some samples of fruit and was associated generally with delay in harvesting.

Air storage late January

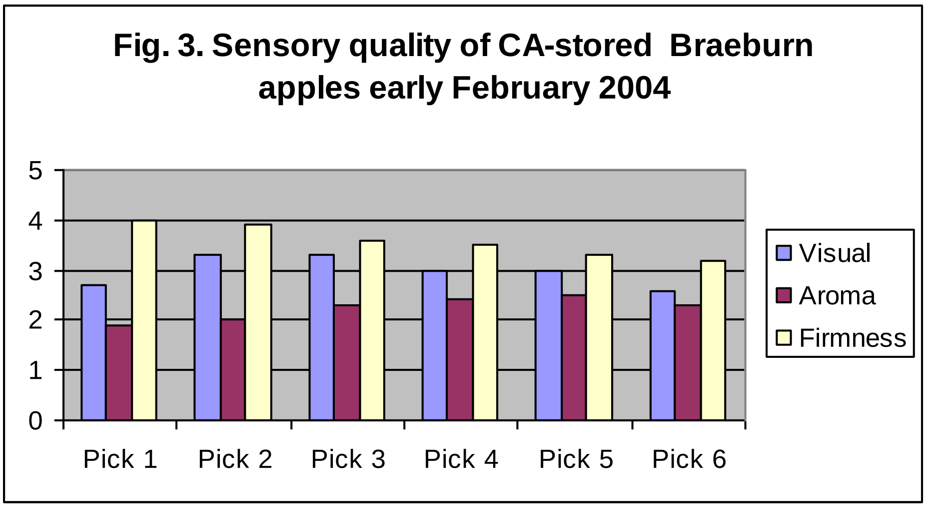
For storage in air until late January scald and core flush development was a constraint (Figure 2). Delay in picking until pick 4 was required to avoid scald although pick 3 may be considered an acceptable commercial risk. Pick 4 was also best for eating quality and had acceptable background colour (2.3) and firmness (6.9 kg). Starch cover (% black), firmness (kg) and soluble solids concentration (%) at pick 4 were 63, 9.0 and 13.5 respectively with a Streif index of 0.18.



Greasiness was scored on a severity basis by a market inspector from WWF and by EMR staff using slightly different scales. There was generally broad agreement and results show clearly the effect of harvest delay in increasing the amount of grease detected on the apples.

CA storage early February

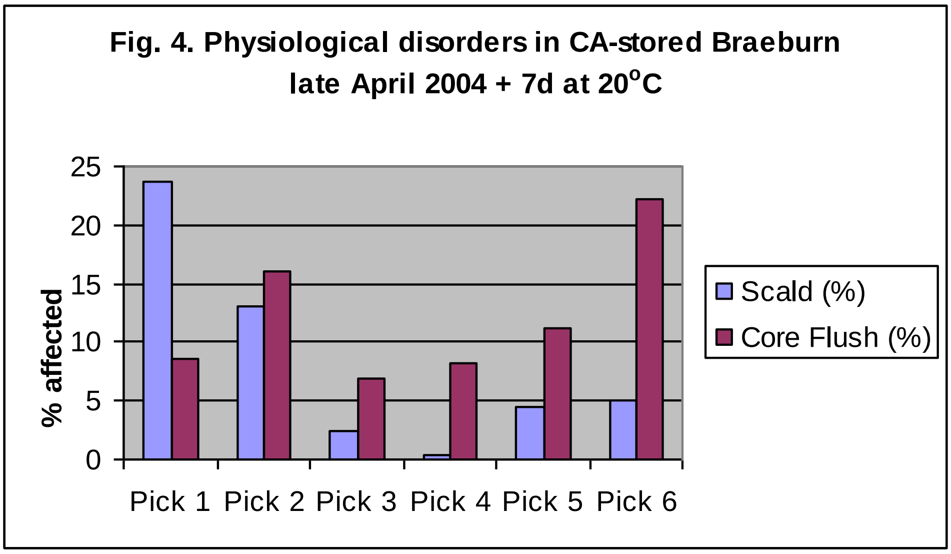
For storage in CA until early February there were no constraints imposed by the development of disorders. Consequently picking date could be directed to achieving the desired appearance, optimum eating quality and least greasiness of the skin. Pick 1 fruit was too immature whilst picks 3 and 4 (16 and 23 October) provided the best combined scores for appearance, aroma and firmness (Figure 3). There were no effects of picking date on any of the other sensory attributes. This is in accordance with the best stage to pick for optimum quality from air storage in late January.



Fruit stored in CA until 2 February 2004 followed by 7 days at 20°C tended to be greasy, particularly those from later picking dates.

CA storage late April

For storage in CA until late April, scald and core flush development were constraints (Figure 4). Pick 4 was the best time to harvest for minimal scald but pick 3 may have provided an acceptable risk. Pick 1 fruit was also visually unacceptable and picks 5 and 6 produced an unacceptable texture in the fruit. None of the picks provided fruit free of all disorders, with core flush development in shelf-life being the biggest problem. Fruit from picks 3 and 4 were still good for background colour (2-2.2) and firmness (7.1-7.3 kg). As found in previous removals of air and CA-stored fruit, the severity of greasiness increased with harvest delay.



Effects of clone

It was not feasible to taste fruit from all six orchards in the study. Consequently, fruit from only one orchard of each clone was tasted. It is possible that any apparent differences in visual or eating quality associated with the different clones may in fact be due to site differences.

In sensory tests done on air-stored fruit in November, Lochbuie was the preferred clone, achieving highest scores for flavour, firmness and texture. Schneider was least preferred, probably on the basis of being too acid and least sweet. In sensory tests done on air-stored fruit in January, Lochbuie was again preferred scoring highest for aroma, sweetness, flavour and overall quality. The remaining clones generally scored similarly for these attributes.

In sensory tests done on CA-stored fruit in February, Schneider was least liked, having scored lower than Lochbuie and Hillwell for sweetness, juiciness, texture and overall acceptance. Apart from flavour, there were no effects of clones on eating quality of fruit stored in CA until April. Lochbuie was considered to have more flavour than Hillwell and, to a lesser extent, than Schneider. Lochbuie was least greasy and may relate to its tendency to be least mature at harvest.

Effects of temperature

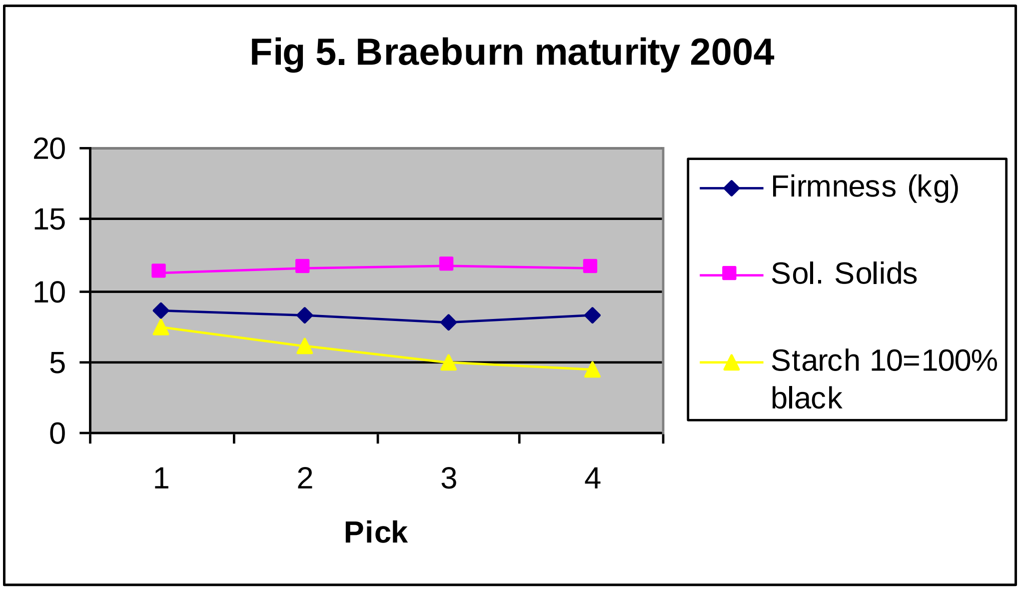
There were no adverse effects of the lower storage temperature (0-0.5°C) and there were some benefits particularly in reducing core flush during prolonged air storage and in reducing scald in prolonged CA storage although storage temperature did not influence greasiness. At the present time the lower storage temperature is preferred but further experience is required before recommendations can be established. It is well known that climatic conditions during the growing season affect the susceptibility of apples to low temperature injury and the work proposed in years 2 and 3 of the project should help to identify the optimum storage temperature.

Outline of results from year 2

The study carried out in 2004 was a repeat of that carried out in the previous year except that fruit for maturity assessment and storage tests were picked on four occasions as opposed to six in 2003. Fruit samples were taken at weekly intervals beginning on 1 October 2004. At one site it was only possible to take samples of Lochbuie apples on the first two occasions. There were insufficient trees left by the picking staff to complete the sampling as planned. Samples of apples from each harvest were removed from air storage on 22 November 2004 and 24 January 2005 and from CA storage on 31 January and 22 April 2005.

Harvest Maturity

On the basis of calendar date, picks 1-4 in 2004 can be compared with picks 2-5 in 2003. The more restricted picking period (3-week) in 2004 may explain the generally less marked effect of harvest delay on maturity parameters compared with the more extended (5-week) period in 2003. Delay in picking was associated with a progressive decline in starch cover although differences between consecutive picks were not always statistically significant (Figure 5). On the basis of starch pattern, it appeared that the fruit in 2004 matured 1-2 weeks earlier than in 2003. There was no significant change in background colour (data not presented) or concentration of soluble solids over the four picks. Pick 1 fruit was firmest and significantly firmer than fruit from pick 3.

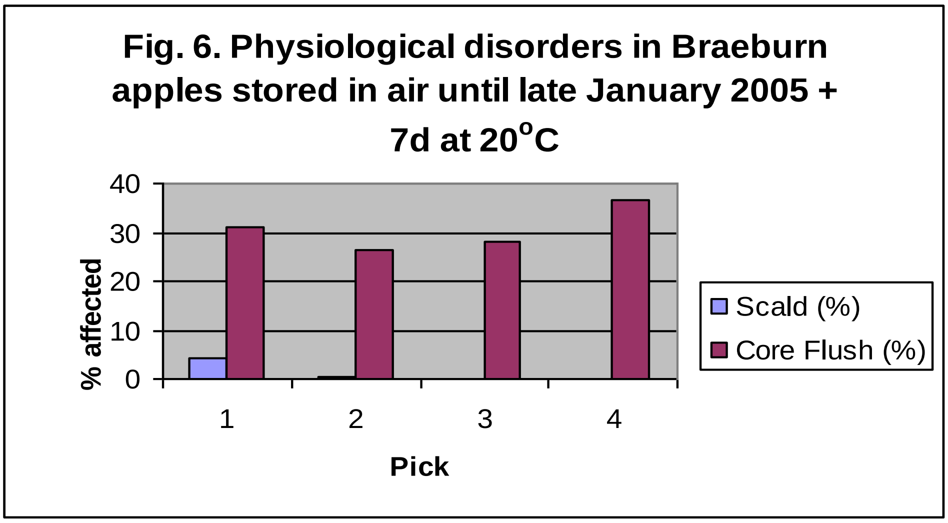


Air storage late November

For storage in air until late November there were no constraints imposed by the development of disorders. This was consistent with results obtained in the previous year. Consequently picking date could be directed to achieving the desired appearance, optimum eating quality and least greasiness of the skin. On the basis of appearance and eating quality pick 1 was clearly too immature. Pick 4 often gave the poorest sensory response and were most greasy. This suggests an optimum period of 8-15 October for short-term air storage.

Air storage late January

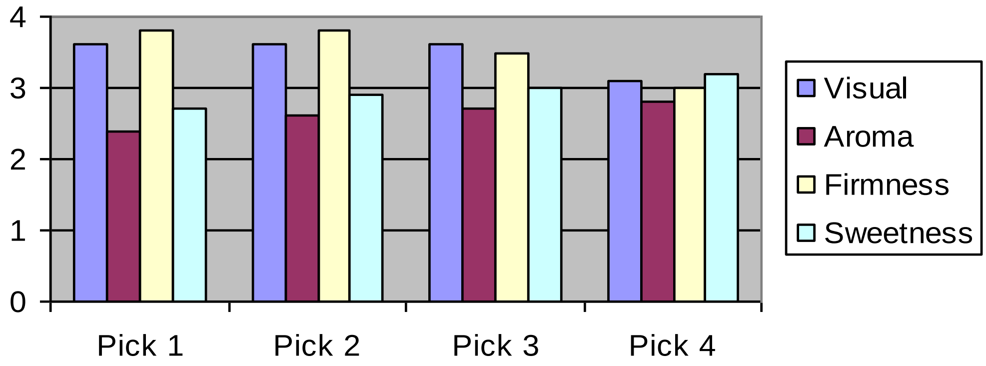
For storage in air until late January core flush and scald development were major and minor constraints respectively (Figure 6). Although scald could be avoided by picking on 8 October or later and storing at 0-0.5^{o}C, it was not possible to avoid core flush by modifying harvest date or storage temperature. Late January was not achievable in air storage in 2004. Generally, on the basis of optimising appearance and eating quality, pick 2 (October 8) was the optimum date. Earlier harvesting was not possible due to scald development and later harvesting was associated with a general loss of visual and eating quality but did not promote physiological disorders.



CA storage late January

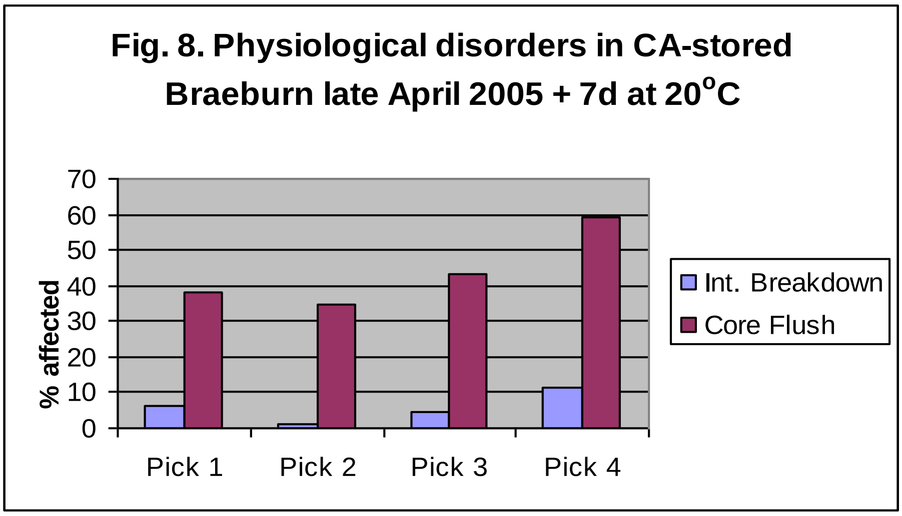
For CA storage until late January core flush was a minor constraint since it developed to a slight extent during ‘shelf-life’. There were insufficient numbers of affected fruit to give reliable indications of treatment effects but there appeared to be little influence of harvest date, clone or storage temperature. Consequently, consideration of optimum harvest dates and storage temperatures for CA storage until late January was mainly concerned with physical and sensory assessments of quality. On this basis, 8-15 October 2004 (picks 2 and 3) appeared to be the best period for harvesting since they provided the highest combined scores for sensory attributes (Figure 7).

Fig. 7. Sensory quality of CA-stored Braeburn apples late January 2005



CA storage late April

For storage in CA until late April, core flush and internal breakdown were major and minor constraints respectively (Figure 8). Clearly late April was not achievable in CA storage in 2004. Core flush was also evident in commercial fruit marketed late in the season. Late picking (pick 4) and storage at low temperature (0-0.5^{o}C) exacerbated the problem, but the problem could not be ameliorated by earlier harvesting and storing at higher temperatures. On the basis of physical and sensory assessments of quality, it appeared that the first two picks (1-8 October) were appropriate for longer storage in CA. It is commonly expected that longer storage requires harvesting at a less mature stage. Core flush development in the 2004 crop dictated a shorter period of storage, where it is assumed that a pick date around 8 October might be ideal. Greasiness increased progressively with harvest delay.



Effects of clone

In air storage Schneider apples developed more core flush than Hillwell or Lochbuie. There was insufficient scald to determine any clonal differences. Hillwell apples had a more yellow background colour and were greasier than either Schneider or Lochbuie. Lochbuie apples were the firmest and Schneider apples were softest with least soluble solids. Lochbuie apples lost most weight during storage. The higher firmness and weight loss associated with Lochbuie was consistent with results obtained in the previous year.

In CA storage breakdown was restricted mainly to Lochbuie picked on the first or final occasion. In both 2003 and 2004 Lochbuie was more affected by core flush and low temperature breakdown than Schneider or Hillwell.

Clonal differences in fruit firmness and soluble solids concentration noted at harvest and in air storage persisted during CA storage. Lochbuie fruits were the firmest and Schneider the softest. Schneider fruits were lowest in soluble solids. As in air storage Lochbuie apples lost most weight during CA storage and Hillwell apples were most greasy.

In sensory tests Lochbuie scored highest for texture which is consistent with results obtained with the penetrometer tests. Hillwell was greasiest, sweetest and most aromatic. These effects may relate to differences in harvest maturity parameters. At harvest Hillwell had the most yellow background colour and contained the highest concentration of soluble solids whilst Lochbuie was firmest.

Effects of temperature

Storing in air at 0-0.5°C as opposed to 1.5-2°C prevented core flush in fruit stored until 24 January 2005 and reduced by 50% the incidence of core flush in fruit after 7 days at 20°C. The lower storage temperature also tended to reduce scald incidence and is consistent with the effect of temperature on scald in CA-stored fruit in the previous year. Additional benefits of storing Braeburn apples at 0-0.5°C as opposed to 1.5-2°C were higher firmness and lower weight loss.

The lower storage temperature resulted in a lower weight loss in fruits stored in CA, as was the case in air stored fruit. However, there were no benefits of the lower storage temperature on fruit colour, firmness or soluble solids concentration. In view of the worsening effect of the lower storage temperature on core flush and the lack of any benefits on quality attributes, it appears that a temperature of 1.5-2°C is more appropriate for CA storage.

Harvest maturity for optimum storage

Harvest maturity parameters associated with optimum storage performance in 2004 were as follows:

Storage details	**Harvest date**	**Harvest maturity parameters**		
		Firmness (kg)	**Starch (% black)**	**Streif index**
Air late Nov.	8 October	8.2	61	0.18
	15 October	7.8	49	0.13
Air late Jan.	8 October	8.2	61	0.18
CA late Jan.	8 October	8.2	61	0.18
	15 October	7.8	49	0.13
CA late April	1 October	8.6	74	0.31
	8 October	8.2	61	0.18

Maturity parameters associated with optimum storage in 2003 and 2004 can be compared as follows:

Storage details	**Year**	**Harvest maturity parameters**		
		Firmness (kg)	**Starch (% black)**	**Streif index**
Air late Jan.	2003	9.0	63	0.18
	2004	8.2	61	0.18
CA late April	2003	9-9.5	63-67	0.18-0.22
	2004	8.2-8.6	61-74	0.18-0.31

It was reassuring that in both years the starch iodine test and Streif Index could be used to indicate optimum time of harvest. Firmness was too variable to be of use as a guide to harvest date. Picking earlier than indicated by starch and Streif index is likely to lead to loss of eating quality but more importantly to wastage due to scald development. Later harvesting will lead to loss of appearance and eating quality and is only appropriate for shorter term storage.

Based on two years of results the most appropriate storage temperature for air and CA-stored fruit appeared to be 0-0.5°C and 1.5-2°C respectively. Different CA regimes had not been tried so advice to the industry was to continue with <1% CO_2 + 2% O_2 for the time being and to establish CA conditions 3 weeks after loading to avoid potential injury to the fruit. The length of storage that is possible will depend on the growing conditions in any particular season and it appears that in years such as 2003 the main risk will be scald whilst in other years such as 2004 the main risk will be core flush. Results suggest that air storage should be terminated by the end of December and CA storage by the end of February or early March. Further years of storage data would be required in order to be able to predict the risk of core flush and scald using weather data.

There may be scope for reducing the main storage disorders of Braeburn i.e. scald and core flush by the use of lower store oxygen concentrations and by shortening the delay before establishing CA conditions. It is hoped that these aspects can be investigated in the final year of the project.

Targets for year 3

Results from years 1 and 2 of the project established safe and effective storage temperatures for air and CA-stored Braeburn apples. In year 3 of the project it was considered unnecessary to carry out further work to compare the effects of storage temperature. Consequently, in year 3 all air-stored samples were kept at 0-0.5°C and all CA-stored samples at 1.5-2°C. In year 3 there was an opportunity to determine the effects of storing fruit at an oxygen concentration below the 2% used in years 1 and 2 of the project. In addition, it was possible to carry out a preliminary assessment of the need to delay establishment of CA conditions. It is clear that for growers without the ability to generate nitrogen for flushing their stores the establishment of CA conditions by fruit respiration would be much slower than recommended for other cultivars (see Defra Best Practice Guide for UK Apple Production, 2001) and may adversely affect storage quality. Braeburn apples, particularly when thoroughly cooled, have a very low rate of respiration which will result in low rates of CA establishment even in stores that meet the requirements for gas tightness.

The targets for year 3 were as follows:

- To continue studies to relate storage quality to harvest date with a view to producing robust maturity parameters to guide commercial harvesting.
- To compare the quality of fruit stored in 2% with that in 1.2% O_2 (<1% CO_2)
- To compare the effects of normal (sealed after cooling and CA achieved within 14 days) and delayed (sealed 3 weeks from loading and nitrogen flushed) establishment of CA conditions (2% O_2, <1% CO_2).

Materials and Methods

Braeburn apples from six commercial orchards were used in the study. These were the same orchards that were used in the previous two years of the project. There were two orchards for each of the three clones (Hillwell, Lochbuie and Schneider) currently favoured by UK growers. Orchards of all three clones were present on one of the farms used in the study, but the remaining three orchards were on different farms and, as a consequence, any potential clonal differences were likely to be confounded by effects of orchard location.

Samples of fruit for maturity assessment and storage tests were picked on four occasions at weekly intervals beginning on 3 October 2005. Fruits above 65 mm diameter were selected at random from trees reserved for the study. After picking, all fruit was transported immediately to the Jim Mount Building at EMR.

Fruit was selected at random from the crop from each orchard to form 20-fruit samples for maturity assessment and for storage in air at 0-0.5^{o}C and controlled atmosphere (CA) conditions at 1.5-2^{o}C. Storage samples were weighed and placed into 360 L containers on the same day as picking. Storage treatments were as follows:

Atmosphere	Temp.	Picks	CA establishment	
			After cooling	3 wk delay
Air	0-0.5ºC	1,2,3,4		
2% O_2 (<1%CO_2)	1.5-2ºC	1,2,3,4		Yes
2% O_2 (<1%CO_2)	1.5-2ºC	2,3	Yes	
1.2% O_2 (<1%CO_2)	1.5-2ºC	2,3		Yes

Based on information from abroad the establishment of CA conditions is normally delayed for 3 weeks to reduce susceptibility to Braeburn Browning Disorder (BBD). After the delay CA (low oxygen) conditions were established by flushing the containers with nitrogen. Where containers were sealed immediately after cooling the oxygen was allow to decrease naturally, i.e. by fruit respiration. However, the reduction in oxygen was too slow to meet the target of achieving conditions (2% O_2) within 14 days from loading and on two occasions the oxygen 'pull-down' rate was accelerated by the use of nitrogen gas. Carbon dioxide produced by fruit respiration was removed continuously using hydrated lime scrubbers. Oxygen concentrations were maintained at 1.2% or 2% by automated injection of compressed air. Gas measurement and control was achieved using an ICA 66 Storage Control System (International Controlled Atmosphere Ltd).

Measurements on samples taken at harvest for maturity assessment included background colour, 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.

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

Fruit firmness. Two measurements were made on the opposite sides of each fruit using an 'Effigi' penetrometer mounted in a drill-stand and fitted with an 11mm probe. Measurements were made in the equatorial region after removal of the peel. Firmness was the maximum force (kg) recorded during the insertion of the probe to a depth of 8mm.

Soluble solids concentration. Juice was extracted from each apple using a steel rod and the soluble solids concentration (%) was measured using a PR-32a digital refractometer (Atago Ltd).

Starch test. Half of each apple was dipped in a solution containing 0.1% w/v iodine and 4% w/v potassium iodide. Dipped sections were left for at least 30 minutes before being assessed. The percentage of the cut surface stained black was estimated with the aid of transparent sheets printed with a series of gauges (concentric rings of decreasing radii) (Cockburn and Sharples, 1979).

The Streif maturity index was calculated by dividing the firmness value expressed in Newtons (kg*9.81) by the product of the soluble solids concentration (%) and starch cover (%) subtracted from 100. Samples of apples from each harvest were removed from air storage on 5 December 2005 and 23 January 2006 and from CA storage on 30 January and 24 April 2006. After weighing, one set of samples was used for an immediate assessment of quality (background colour, firmness and soluble solids concentration) and a similar set of samples was transferred to containers in air at 20^{o}C. Samples previously stored in air at 0-0.5^{o}C and in CA (2% O_2 with 3 weeks delay only) at 1.5-2^{o}C were removed after 4 days and examined for greasiness and a few apples were used for sensory evaluation by representatives of WWF and EMR. The remainder of the samples were placed back into 20^{o}C. Samples were removed after 7 days at 20^{o}C for an assessment of external and internal condition. Each fruit was examined externally for the presence of rotting and external physiological disorders such as superficial scald. Finally all the fruits were cut and examined for internal physiological disorders.

Statistical analysis

All data were subjected to an analysis of variance (ANOVA) using a treatment structure to compare the effects of picking dates and clones and any possible interaction. For the storage data CA condition was an additional factor in the analysis (restricted to fruit from picks 2 and 3). The overall effects of picking dates, clones and CA treatments can be compared using the standard errors of the difference between means (SED) and degrees of freedom (df) given in the tables.

Results and Discussion

Harvest maturity (Table 1)

On the basis of calendar date picks, 1-4 in 2005 and 2004 can be compared with picks 2-5 in 2003. Delay in picking was associated with a progressive loss of greenness and starch cover and a progressive increase in the concentration of soluble solids although differences between consecutive picks were not always statistically significant.

On the basis of starch pattern, it appeared that the fruit in 2005 were of similar maturity to fruit harvested in 2003, but the data for soluble solids and firmness indicated that 2004 and 2005 were more similar in their maturity at harvest. The Streif maturity index changed in a manner similar to that described for starch cover. There was no significant change in firmness over the four picks although fruit from picks 1 and 2 were firmest and fruit from pick 4 the softest.

Storage behaviour in air and CA

Susceptibility to rotting and physiological disorders normally determines the maximum period of storage that is possible for any particular variety in any given storage environment. Within the period that apples remain in a sound condition the eating quality of the fruit will dictate the period of storage that provides acceptable commercial quality.

Air storage

Physiological disorders and rotting

Fruit stored in air until 23 January 2006 followed by a further 7 days at 20°C was free of fungal rots (data not presented). There were no disorders in fruit examined immediately after storage in air until 5 December 2005 and none developed during a further 7 days at 20°C. However, where air storage was extended until 23 January 2006 scald and core flush affected an average of 1.1% and 5.8% of fruits examined after a further 7 days at 20°C (Tables 19 and 21). Although the average incidence of scald was similar to that recorded in the previous year, (1.2%) the incidence of core flush was much less than in the 2004 crop (30.4%).

As in the previous year, scald developed only in fruit from picks 1 and 2 (Table 19). Fruit picked on an equivalent calendar date in 2003 or earlier were also the only fruit to develop scald. Scald could be avoided by picking on 17 or 24 October 2005. Core flush was a more serious problem than scald and dictated that the 2005 crop could not be stored in air until late January. There was no effect of picking date on the incidence of core flush consequently, unlike the situation with scald; there is no prospect for avoidance of the core flush problem by adjusting the harvesting period. December appears to be the limit for air-stored Braeburn.

As in the previous year, Schneider apples developed significantly more core flush than Hillwell and tended to be more affected than Lochbuie (Table 21). There was insufficient scald to determine any clonal differences.

Fruit quality measurements

There were only slight changes in the measured quality parameters (colour, firmness and soluble solids) in the period 5 December 2005 to 23 January 2006.

Lochbuie apples were firmer and lost more weight during storage than either Schneider or Hillwell (Tables 16 and 18). These effects were consistent with results obtained in the previous two years. Schneider apples contained higher soluble solids than either Lochbuie or Hillwell (Table 17). There was no effect of clone on background colour (Table 15).

Firmness declined progressively with delay in picking but the effect failed to reach statistical significance (Table 16). There were no significant effects of harvest date on background colour or soluble solids concentration (Tables 15 and 17). As found previously earlier picked fruit (picks 1 and 2) lost more weight in store than that picked later (picks 3 and 4) (Table 18).

Fruit stored in air 0-0.5^{o}C followed by a further 4 days at 20^{o}C were assessed for greasiness on a 0-5 scale by WWF QA staff. By comparing greasiness scores with comments made by QA staff it appeared that greasiness scores above 1 are unlikely to be commercially acceptable. Greasiness increased progressively with delay in harvesting and with increased storage time (Table 20). In December, pick 3 and 4 fruit were unacceptable and in January only pick 1 fruit was acceptable. Hillwell fruit was most greasy.

CA storage

Physiological disorders and rotting

Fruit stored in CA until 24 April 2006 was virtually free of rotting although the average incidence of rotting increased to 1.1% during a further 7 days at 20°C. There was insufficient rotting to determine any effects of picking date or clone (Tables 22 and 23).

Scald did not develop in fruit stored in CA until 30 January 2006 followed by a further 7 days at 20°C and did not affect fruit removed from CA on 24 April 2006 (Table 19). However, scald developed during a further 7 days at 20°C affecting an average of 3.6% of fruits. There was no effect of clone on scald incidence but there was a significant effect of picking date. The pattern of effects of harvest date on scald incidence was similar to that observed in the first year of the project. Pick 1 fruit was worst affected by scald, pick 2 fruit was unaffected and scald increased with further delay in harvest. In the 2003 crop there was virtually no scald in pick 4 fruit (equivalent calendar date to pick 3 in 2005). The apparent slight increase in scald with further delay in harvest is likely to be a form of senescent scald rather than true superficial scald observed on early-picked fruit.

The development of core flush was the limiting factor in the CA storage of Braeburn in the previous 2 years. In the 2005 crop core flush was not evident in fruit removed from CA storage at the end of January although a low incidence of the disorder (average 0.6%) was recorded in fruit after a further 7 days at 20°C (Table 21). It is unlikely that such a slight amount of core flush would have any commercial significance. However, by 24 April 2006 the average incidence of core flush had increased to 5.4% immediately ex-store and to 11.9% after a further 7 days at 20°C. Although the potential for core flush was much less than in 2003 the problem was sufficient to preclude storage until April using the current CA conditions (<1% CO_2 + 2% O_2) and establishment protocol (3 weeks before sealing). Core flush could not be avoided by adjustment of harvest date. Since there were no examinations of fruit between 30 January and 24 April it is impossible to indicate when the level of core flush first became a problem. Breakdown was generally not a problem affecting an average of only1.1% of fruits stored in CA until 24 April and subjected to after a further 7 days at 20°C (Table 22). As in the previous two years, Lochbuie was more affected by core flush than Schneider or Hillwell although the effect just failed to reach significance at the 5% level (Table 23).

Fruit quality measurements

As found in the previous year, there was virtually no change in the quality (colour, firmness and soluble solids) of CA-stored fruit from January 30 to April 24 2006, despite the increased development of core flush during that period (Tables 15, 16 and 17).

Schneider apples had the most yellow background colour and highest concentration of soluble solids when examined after CA storage until 24 April 2006. As in air storage, Lochbuie apples were the firmest in CA storage and lost most weight (Table 18). Similar results were found in the previous year.

There was a progressive effect of delayed picking on loss of background colour and firmness although these effects just failed to reach statistical significance at the 5% level. There was no effect of harvest date on soluble solids concentration. Fruit picked on the second occasion lost most weight during CA storage until 30 January and 24 April 2006.

Fruit stored in air at 0-0.5°C followed by a further 4 days at 20°C were assessed for greasiness on a 0-5 scale by WWF QA staff (Table 20). By comparing greasiness scores with comments made by QA staff it appeared that greasiness scores above 1 are unlikely to be commercially acceptable. Greasiness increased progressively with delay in harvesting and with increased storage time. In January pick 4 fruit were unacceptable and in April only pick 1 fruit was acceptable. Lochbuie was least greasy.

Sensory assessment of air and CA-stored fruit (Tables 2-14)

The highest visual and eating quality was generally found in CA-stored fruit in late-January although highest aroma scores were ascribed to air-stored fruit in January. The suppressing effect of CA conditions on aroma development is well known for apples in general. Lowest scores for visual quality and for many of the sensory attributes were ascribed to fruit stored in CA until the end of April suggesting that the fruit was stored too long for optimum quality. In the previous year prolonged storage in CA (late April) resulted in lower scores for aroma and sweetness and for visual appearance. In both the 2004 and 2005 crop, extending storage in air and CA resulted in lower scores for firmness and texture. As in 2004, greasiness was similar in air and CA storage and did not get worse with time in store. The fact that fruit stored in CA until April appeared less greasy than similar fruit examined in January may be attributed to fewer assessors (5) being present in April than in January (9).

As in the previous year, pick 4 fruit generally scored lowest for visual quality, acidity, juiciness, firmness, texture and overall acceptability. Conversely, pick 1 fruit scored lowest for aroma. This suggests that picks 2 and 3 provided the best sensory quality in 2005. However, where storage in CA was extended, the second harvest gave slightly higher scores for texture and overall quality. Greasiness increased progressively with harvest delay. Based on the criterion that greasiness scores above 1 are not commercially acceptable picks, 2 and 3 would not be acceptable for CA storage and pick 2 would be marginal for air storage.

As in the previous year, Lochbuie score highest for texture which is consistent with results obtained with the penetrometer tests. Lochbuie was also firmer, juicier, less greasy and preferred overall to Hillwell and Schneider. The sensory qualities of Hillwell and Schneider were generally similar. The overall preference for Lochbuie appears to relate to its superior textural characteristics which in turn may be related to higher firmness of the fruit at harvest (harvest maturity data not presented for individual orchards).

Effect of store oxygen concentration and rate of establishment of CA conditions (Tables 24 and 25)

Storing Braeburn apples (picks 2 and 3 only) in 1.2% O_2 as opposed to 2% O_2 (both conditions established by nitrogen flushing 3 weeks from harvest/loading) resulted in slightly greener fruit ex-store but had no other significant effects on storage quality. Similarly, establishing CA conditions slowly by fruit respiration over 14 days or by nitrogen flushing after 21 days provided similar quality of fruit ex-store. Average levels of rotting were low in fruit from all treatments even after 7 days at 20°C (0.7% in January and 1.6% in April) but least rotting occurred in fruit stored in 2% O_2 and subjected to a 3-week delay in CA establishment.

Preliminary results suggest that it may be safe to seal stores once the fruit has reached the holding temperature (1.5-2°C) and that 1.2% may be used instead of 2% O_2. However, with only one year of data limited to fruit from only 2 harvest dates it is not advised that growers deviate from the recommendation to use 2% O_2 and to establish after a 3-week delay. Clearly, Braeburn suffers no adverse effect of rapid establishment of CA by nitrogen flushing after a 3-week delay. Without nitrogen flushing stores can be sealed sooner than 3 weeks; further work is required to define establishment parameters and minimum store oxygen concentrations.

Conclusions

For storage in air until early December, there were no constraints imposed by the development of disorders. This was consistent with results obtained in the previous year. Consequently, picking date could be directed to achieving the desired appearance, optimum eating quality and least greasiness of the skin. As picking was delayed fruit were generally more aromatic, less acid, sweeter, less firm with a poorer texture but overall quality scores were similar. On the basis of greasiness pick 3 and 4 fruit were unacceptable after shelf-life, suggesting an optimum pick date of 10 October for short-term air storage. This was within the period (8-15 October) suggested as optimum in the previous year.

As found in previous years, the storage of Braeburn apples in air until late January was constrained by the development of core flush and scald. Although scald could have been avoided by picking on 17 October or later, it was not possible to avoid core flush by modifying harvest date. In all three years of the study, late January was not achievable in air storage. In 2005, there was no clear optimum harvest date as regards appearance and eating quality pick. To avoid greasiness, apples would need to have been harvested on the first occasion (October 3) but fruit picked at that time were susceptible to scald. On the basis of three years of results, it will be recommended that Braeburn should not be stored in air after December since development of disorders is likely and greasiness is likely to be a major adverse quality characteristic in fruit purchased by consumers. The extent of disorder development will vary from orchard to orchard and from year to year, and in some circumstances it may be possible to slightly extend the air storage of Braeburn, although this would be at the risk of the grower. The advice is that CA should be used for post-December storage of Braeburn.

For CA storage until late January, there were no constraints imposed by the development of disorders. Consequently, consideration of optimum harvest dates for CA storage until late January was mainly concerned with physical and sensory assessments of quality and lack of greasiness in particular. On this basis, 10-17 October 2005 appeared to be the best period for harvesting, which was similar to the best period in 2004 (8-15 October).

For storage in CA until late April, core flush was a major constraint, whilst scald and internal breakdown were minor constraints. As in previous years, late April was not achievable in CA storage in 2005. Again, the core flush problem could not be ameliorated by earlier harvesting. On the basis of physical and sensory assessments of quality it appeared that the first two picks (3-10 October) were appropriate for longer storage in CA, although potential greasiness of pick 2 fruit could possibly be problematic. It is commonly expected that longer storage requires harvesting at a less mature stage. Undoubtedly, pick 1 fruit would be preferred for the longest period of storage if it was not for the heightened risk of scald. However, since the risk of core flush development dictates termination of storage earlier than April, it is possible that pick 1 fruit would remain free of scald.

Harvest maturity parameters associated with optimum storage performance in 2005 were as follows:

Storage details	**Harvest date**	**Harvest maturity parameters**		
		Firmness (kg)	**Starch (% black)**	**Streif index**
Air early Dec.	10 October	8.6	76	0.33
Air late Jan.	10 October	8.6	76	0.33
CA late Jan.	10 October	8.6	76	0.33
	17 October	8.3	65	0.20
CA late April	10 October	8.6	76	0.33

It is clear from data obtained in all years of the study that the picking ‘window’ is quite narrow for Braeburn. The following criteria were used to identify the optimum harvest date:

- Avoidance of scald
- Background colour maximum score of 2 (light green) on WWF colour chart
- Firmness minimum of 6.8 kg at despatch
- Greasiness maximum score of 1 on 0-5 scale

It was reassuring that over the 3 years the starch iodine test could be used to indicate optimum time of harvest. Firmness was too variable between the years to be of use as a guide to harvest date and there was little change in soluble solids concentrations over the harvesting period. Starch levels suggested for optimum storage quality are as follows:

	Starch	
	% surface black	**Ctifl 1-black, 10-white**
Air storage December	85-75	3-5
CA storage January	85-75	3-5
CA storage March	80*-75	4*-5

* Lower starch coverage required to reduce risk of superficial scald

Picking according to these starch criteria generally provided the best eating quality in each of the years.

Picking earlier than indicated by starch levels is likely to lead to poor appearance, loss of eating quality and wastage due to scald development. Later harvesting will lead to greasiness, loss of appearance and eating quality and is only appropriate for shorter term storage.

Based on current information, the storage temperature for air and CA-stored fruit should be 0-0.5°C and 1.5-2°C respectively. The CA conditions should remain at <1% CO_2 + 2% O_2 for the time being and CA conditions should be established 3 weeks after loading to avoid potential injury to the fruit. The length of storage that is possible will depend on the growing conditions in any particular season and it appears that in years such as 2003 the main risk will be scald, whilst in other years such as 2004 the main risk will be core flush. From current information, it is suggested that air storage should be terminated by the end of December and CA storage by the end of February or early March. Further years of storage data would be required in order to be able to predict the risk of core flush and scald using weather data.

On the basis of results obtained in 2005, it appears safe to seal CA stores as soon as the fruit reaches storage temperature and that the 3-week delay in sealing may be unnecessary. However, further years of data would be required before a recommendation could be made to seal stores sooner than 3 weeks. In view of the time taken to achieve CA conditions following a 3-week delay, growers should consider the use of nitrogen flushing to obtain low oxygen conditions. There appears to be a little advantage in storing Braeburn at 1.2% O_2 but this is based on only one year of data.

None of the clones tested scored highest for all aspects of storage. Although Lochbuie was consistently the firmest clone and often least greasy, it developed most core flush in CA storage. The information provided to growers on harvest maturity parameters and storage conditions are considered relevant to all clones tested.

Technology transfer

Data from the project were used to formulate picking date advice provided by the Quality Fruit Group (QFG) in 2004 and 2005. Reference was made to the study at various conferences such as the FAST Conference held at EMR in February 2005 and at the EMRA / MFSS Storage Day held at EMR in April 2005 and March 2006.

References

Defra Best Practice Guide for UK Apple Production (2001).

Cockburn, J.T. & Sharples, R.O. (1979). A practical guide for assessing starch in Conference pears. *Rep. E. Malling Res. Stn for 1978*, 215-16.

Smith, S.M. 1985. *Measurement of the quality of apples*. Office for Official Publications of the European Communities, Luxembourg.

Appendices

None.

Table 1. The effects of picking dates and clones on maturity parameters of Braeburn apples in 2005. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Colour	**Firmness**	**S. Solids**	**Starch**	**Streif**
	1, green -4, yellow	**(kg)**	**(%)**	**(% black)**	**Index**
Schneider	1.6	8.4	11.8	71.0	0.31
Hillwell	1.5	8.1	11.3	68.4	0.26
Lochbuie	1.4	8.7	11.4	68.9	0.28
SED (12 df)	0.07	0.22	0.14	3.44	0.040
Pick 1	1.4	8.5	11.0	82.9	0.45
Pick 2	1.5	8.6	11.5	75.5	0.33
Pick 3	1.5	8.3	11.7	64.5	0.20
Pick 4	1.6	8.1	11.7	54.9	0.15
SED (12 df)	0.08	0.25	0.17	3.98	0.046

Table 2. The effects of picking date on the visual (greasiness) quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	**Pick 2**	**Pick 3**	**Pick 4**
Air December	1.0	1.2	1.8	2.4
Air January	0.9	1.2	1.8	2.5
CA January	0.5	1.0	2.1	2.8
CA April	0	0.3	0.7	1.0
SED (32 df)	0.53			

Table 3. The effects of picking date on the visual quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	**Pick 2**	**Pick 3**	**Pick 4**
Air December	3.2	3.1	3.1	2.8
Air January	3.1	3.0	2.9	3.0
CA January	3.6	3.6	3.4	3.2
CA April	2.9	3.0	2.5	2.1
SED (32 df)	0.50			

Table 4. The effects of picking date on the sensory (aroma) quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	Pick 2	Pick 3	Pick 4
Air December	1.7	2.0	2.1	2.2
Air January	2.3	2.3	2.5	2.5
CA January	1.8	1.7	2.0	2.1
CA April	1.5	1.7	1.7	1.8
SED (32 df)	0.26			

Table 5. The effects of picking date on the sensory (acidity) quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	Pick 2	Pick 3	Pick 4
Air December	2.5	2.4	2.5	2.2
Air January	2.5	2.3	2.2	2.2
CA January	2.3	2.2	2.1	1.9
CA April	2.4	1.9	1.8	1.6
SED (32 df)	0.21			

Table 6. The effects of picking date on the sensory (sweetness) quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	Pick 2	Pick 3	Pick 4
Air December	2.6	2.4	2.7	2.8
Air January	2.6	2.5	2.7	2.8
CA January	2.7	2.8	2.9	2.9
CA April	2.4	2.5	2.7	2.4
SED (32 df)	0.20			

Table 7. The effects of picking date on the sensory (flavour) quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	Pick 2	Pick 3	Pick 4
Air December	2.7	2.7	2.9	3.0
Air January	2.8	2.7	2.9	2.8
CA January	3.1	3.3	3.4	3.2
CA April	2.6	2.6	2.5	2.2
SED (32 df)	0.19			

Table 8. The effects of picking date on the sensory (juiciness) quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	**Pick 2**	**Pick 3**	**Pick 4**
Air December	3.4	3.6	3.5	3.6
Air January	3.3	3.2	3.3	3.1
CA January	3.4	3.5	3.7	3.5
CA April	3.2	2.9	2.8	2.7
SED (32 df)	0.20			

Table 9. The effects of picking date on the sensory (firmness) quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	**Pick 2**	**Pick 3**	**Pick 4**
Air December	3.7	3.7	3.6	3.3
Air January	3.3	3.1	2.8	2.8
CA January	3.9	3.8	3.6	3.3
CA April	3.8	3.3	3.0	2.7
SED (32 df)	0.30			

Table 10. The effects of picking date on the sensory (texture) quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	**Pick 2**	**Pick 3**	**Pick 4**
Air December	3.6	3.6	3.5	3.4
Air January	3.3	3.1	3.0	3.0
CA January	3.9	3.8	3.7	3.4
CA April	3.8	3.3	2.9	2.8
SED (32 df)	0.31			

Table 11. The effects of picking date on the sensory (overall) quality of Braeburn apples stored at 0-0.5ºC in air until 5 December 2005 and 23 January 2006 and at 1.5-2ºC in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	**Pick 2**	**Pick 3**	**Pick 4**
Air December	2.9	2.9	3.1	3.1
Air January	3.0	2.9	2.8	2.7
CA January	3.4	3.6	3.5	3.2
CA April	3.0	2.9	2.6	2.4
SED (32 df)	0.20			

Table 12. The overall effects of clones on the sensory quality of Braeburn apples stored at 0-0.5°C in air until 5 December 2005 and 23 January 2006, and 1.5-2°C in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20°C

	Lochbuie	**Hillwell**	**Schneider**	**SED**	**df**
Greasiness	0.8	1.8	1.4	0.26	36
Visual	3.1	3.5	2.6	0.12	36
Aroma	1.8	2.1	2.1	0.09	36
Acidity	2.1	2.4	2.1	0.09	36
Sweetness	2.7	2.6	2.7	0.07	36
Flavour	2.9	2.7	2.9	0.07	36
Juiciness	3.5	3.3	3.1	0.07	36
Firmness	3.7	3.1	3.2	0.11	36
Texture	3.7	3.2	3.2	0.10	36
Overall	3.2	2.9	2.9	0.08	36

Table 13. The overall effects of picking date on the sensory quality of Braeburn apples stored at 0-0.5°C in air until 5 December 2005 and 23 January 2006, and 1.5-2°C in CA until 30 January and 24 April 2006. Fruit was assessed after 4 days at 20°C. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	**Pick 2**	**Pick 3**	**Pick 4**	**SED (32 df)**
Greasiness	0.6	0.9	1.6	2.2	0.26
Visual	3.2	3.2	3.0	2.8	0.25
Aroma	1.8	1.9	2.1	2.2	0.13
Acidity	2.4	2.2	2.1	2.0	0.10
Sweetness	2.6	2.6	2.8	2.7	0.10
Flavour	2.8	2.8	2.9	2.8	0.09
Juiciness	3.3	3.3	3.3	3.2	0.10
Firmness	3.7	3.5	3.3	3.0	0.15
Texture	3.7	3.4	3.3	3.1	0.15
Overall	3.1	3.1	3.0	2.8	0.10

Table 14. The overall effects of storage conditions and duration on the sensory quality of Braeburn apples stored at 0-0.5°C in air until 5 December 2005 (Air 1) and 23 January 2006 (Air 2), and 1.5-2°C in CA until 30 January (CA 1) and 24 April (CA 2) 2006. Fruit was assessed after 4 days at 20°C.

	Air 1	**Air 2**	**CA 1**	**CA 2**	**SED (32 df)**
Greasiness	1.6	1.6	1.6	0.5	0.26
Visual	3.1	3.0	3.4	2.6	0.25
Aroma	2.0	2.4	1.9	1.7	0.13
Acidity	2.4	2.3	2.1	1.9	0.10
Sweetness	2.6	2.7	2.8	2.5	0.10
Flavour	2.8	2.8	3.2	2.5	0.09
Juiciness	3.5	3.2	3.5	2.9	0.10
Firmness	3.6	3.0	3.7	3.2	0.15
Texture	3.5	3.1	3.7	3.2	0.15
Overall	3.0	2.8	3.4	2.7	0.10

Table 15. The effects of clones and picking dates on the background colour (WWF chart where 1 is green and 4 is yellow) of Braeburn apples stored in air and CA conditions (<1% CO_2 + 2% O_2). Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Air		**CA**	
	5.12.05	**23.1.06**	**30.1.06**	**24.4.06**
Schneider	1.8	2.1	1.9	1.9
Hillwell	1.6	2.0	1.9	1.8
Lochbuie	1.8	1.9	1.7	1.7
SED (12 df)	0.26	0.10	0.10	0.07
Pick 1	1.6	1.9	1.6	1.7
Pick 2	1.6	1.9	1.8	1.8
Pick 3	1.9	2.0	1.9	1.9
Pick 4	1.9	2.1	2.0	1.9
SED (12 df)	0.30	0.12	0.12	0.08

Table 16. The effects of clones and picking dates on the firmness (kg) of Braeburn apples stored in air and CA conditions (<1% CO_2 + 2% O_2). Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Air		**CA**	
	5.12.05	**23.1.06**	**30.1.06**	**24.4.06**
Schneider	8.4	7.8	8.1	7.7
Hillwell	8.0	7.7	7.8	7.6
Lochbuie	8.8	8.4	8.5	8.3
SED (12 df)	0.17	0.23	0.22	0.19
Pick 1	8.6	8.3	8.4	8.1
Pick 2	8.4	8.0	8.3	8.1
Pick 3	8.3	7.9	8.1	7.8
Pick 4	8.2	7.6	7.7	7.5
SED (12 df)	0.19	0.27	0.26	0.21

Table 17. The effects of clones and picking dates on the soluble solids concentration (%) of Braeburn apples stored in air and CA conditions (<1% CO_2 + 2% O_2). Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Air		**CA**	
	5.12.05	**23.1.06**	**30.1.06**	**24.4.06**
Schneider	13.3	13.0	13.3	13.2
Hillwell	12.8	12.3	12.6	12.4
Lochbuie	12.9	12.5	12.7	12.8
SED (12 df)	0.19	0.16	0.23	0.27
Pick 1	12.8	12.6	12.8	12.8
Pick 2	13.1	12.6	13.0	12.9
Pick 3	13.2	12.7	12.8	12.7
Pick 4	12.9	12.4	13.0	12.7
SED (12 df)	0.21	0.19	0.27	0.31

Table 18. The effects of clones and picking dates on the weight loss (%) of Braeburn apples stored in air and CA conditions (<1% CO_2 + 2% O_2). Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Air		**CA**	
	5.12.05	**23.1.06**	**30.1.06**	**24.4.06**
Schneider	0.61	1.12	0.81	1.03
Hillwell	0.65	1.22	0.78	0.99
Lochbuie	0.82	1.48	1.10	1.28
SED (12 df)	0.042	0.083	0.074	0.085
Pick 1	0.70	1.37	0.73	0.89
Pick 2	0.89	1.33	1.26	1.39
Pick 3	0.57	1.21	0.77	1.01
Pick 4	0.59	1.17	0.81	1.11
SED (12 df)	0.048	0.096	0.085	0.099

Table 19. The effects of clones and picking dates on the incidence (%) of superficial scald in Braeburn stored in air and CA conditions (<1% CO_2 + 2% O_2). Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

Removal date	**Air**		**CA**	
	23.1.06		**24.4.06**	
Days at 20ºC	**0**	**7**	**0**	**7**
Schneider	0	1.4	0	6.5
Hillwell	0	0	0	2.2
Lochbuie	0	1.9	0	2.3
SED (12 df)	-	1.14	-	2.63
Pick 1	0	3.5	0	10.1
Pick 2	0	0.8	0	0
Pick 3	0	0	0	1.7
Pick 4	0	0	0	2.7
SED (12 df)	-	1.32	-	3.04

Table 20. The effects of clones and picking dates on the severity (max. 5) of greasiness in Braeburn apples stored in air and CA conditions (<1% CO_2 + 2% O_2). Assessments made by WWF staff after 4 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

Removal date	**Air**		**CA**	
	5.12.05	**23.1.06**	**30.1.06**	**24.4.06**
Schneider	0.9	1.6	1.0	2.0
Hillwell	1.8	2.1	1.2	2.1
Lochbuie	1.4	1.2	0.8	1.6
SED (12 df)	0.25	0.17	0.17	0.19
Pick 1	0.5	0.8	0.2	1.2
Pick 2	1.2	1.5	0.8	1.8
Pick 3	1.7	1.9	1.1	2.2
Pick 4	2.0	2.3	1.7	2.4
SED (12 df)	0.28	0.20	0.19	0.22

Table 21. The effects of clones and picking dates on the incidence (%) of core flush in Braeburn apples stored in air and CA conditions (<1% CO_2 + 2% O_2). Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

Removal date	**Air**		**CA**			
	23.1.06		**30.1.06**		**24.4.06**	
Days at 20ºC	0	7	0	7	0	7
Schneider	0	13.7	0	1.7	7.5	8.7
Hillwell	0	0	0	0	2.5	7.1
Lochbuie	0	3.8	0	0	6.2	19.8
SED (12 df)	-	4.92	-	-	4.45	5.64
Pick 1	0	10.6	0	0	3.3	13.5
Pick 2	0	6.6	0	0	11.7	13.0
Pick 3	0	1.9	0	0	1.7	7.1
Pick 4	0	4.2	0	2.2	5.0	13.8
SED (12 df)	-	5.68	-	-	5.14	6.52

Table 22. The effects of picking date on the incidence of rotting and physiological disorders in Braeburn apples stored CA conditions (<1% CO_2 + 2% O_2) until 24 April 2006 followed by 7 days at 20ºC. Dates for picks 1, 2, 3 and 4 were 3, 10, 17 and 24 October 2005 respectively

	Pick 1	**Pick 2**	**Pick 3**	**Pick 4**	**SED**	**df**
Rotting (%)	0.8	1.0	0	2.5	1.62	12
Core flush (%)	13.5	13.0	7.1	13.8	6.52	12
Internal breakdown (%)	0	2.5	0	2.0	1.94	12

Table 23. The effects of clones on the incidence of rotting and physiological disorders in Braeburn apples stored controlled atmosphere conditions (<1% CO_2 + 2% O_2) until 24 April 2006 followed by 7 days at 20ºC

	Schneider	Hillwell	Lochbuie	SED	Df
Rotting (%)	1.9	0.8	0.6	1.40	12
Core flush (%)	8.7	7.1	19.8	5.64	12
Internal breakdown (%)	1.5	0	1.9	2.24	12

Table 24. Effect of store oxygen concentration (<1% CO_2) and delay in establishing CA conditions on the quality of Braeburn apples stored at 1.5-2ºC. Data are means for fruit harvested on 10 and 17 October 2005 and for fruit removed from store on 30 January and 24 April 2006

Store oxygen conc. (%)	**2%**		**1.2%**	**SED (66 df)**
Delay in CA	**3 wk**	**None**	**3 wk**	
Colour 1, green – 4, yellow	1.84	1.78	1.72	0.047
Firmness (kg)	8.1	8.2	8.3	0.13
S. Solids (%)	12.8	12.9	12.8	0.12
Wt Loss (%)	1.11	1.31	1.21	0.104
Rotting (%)	0.3	0.1	0.8	0.42
Core Flush (%)	3.3	4.6	1.7	2.13

Table 25. Effect of store oxygen concentration (<1% CO_2) and delay in establishing CA conditions on the quality of Braeburn apples stored at 1.5-2ºC followed by 7 days at 20ºC. Data are means for fruit harvested on 10 and 17 October 2005 and for fruit removed from store on 30 January and 24 April 2006

Store oxygen (%)	**2%**		**1.2%**	**SED (66 df)**
Delay in CA	**3 wk**	**None**	**3 wk**	
Rotting (%)	0.3	1.3	1.9	0.63
Superficial scald (%)	0.4	0.7	0	0.44
Core Flush (%)	10.1	7.2	7.3	1.96
Internal breakdown (%)	0.6	0	0	-