Project title:	Alternative strategies for reducing wastage in stored apple fruit
Project number:	TF 31 [Previously APRC SP 31]
Report:	Reports 1991-1997
Project leader:	Dr D Johnson, HRI East Malling
Key words:	apple, storage, wastage, rotting

This project report was originally issued by the Apple & Pear Research Council, under project number SP 31.

SP31: Alternative strategies for reducing wastage in stored apple fruits

(A) Low ethylene and ultra-low oxygen concentrations for control of rotting in Cox

During the week of 22nd April 1991 an examination was made of samples of Cox apples which had been stored at 3.5°C in 0.75%, 1% and 1.25% O_2 (<1% CO_2), and samples stored at 3.5°C in 1.25% O_2 (<1% CO_2) with and without ethylene removal.

Low ethylene trial. There was no effect of ethylene removal on the incidence of rotting of samples either inoculated or not inoculated with Nectria spores immediately after harvest even though firmness was retained more effectively where ethylene was removed from the store atmosphere. Overall about 60% of inoculated fruits had rotted, compared with 20% of uninoculated fruits.

Ultra-low oxygen trial. Only uninoculated samples had been carried through to this stage of the trial, and fruit from 8 sites was represented. There was, overall, a reduction in rotting from 8.3 to 5.8% by reducing store oxygen from 1.25% to 0.75%. Half of this reduction could be accounted for by a reduction in contact rots.

Uninoculated samples, from the site which was represented in both trials, rotted to the same extent when stored at the same oxygen concentration. This suggests that the different levels of rotting of inoculated fruit in the two trials, observed at the first inspection (11th March), probably resulted from a difference in inoculation technique, rather than from a difference in storage methodology.

J. Stow, D. Johnson, Pia Genge, C. Dover

(B) Ultra-low oxygen concentrations for the control of superficial scald in Bramley

The incidence of superficial scald increased considerably from that indicated in the last report (9th April 1991). There is now a clear effect of oxygen concentration on scald control. Only fruit stored in 0.4% O_2 was free of scald after 217 days storage, with 5% of fruit stored in 0.6% O_2 showing symptoms of the disorder and an increasing incidence of scald in higher oxygen concentrations. At the last inspection (252 days) scald was evident on fruit from all storage regimes in this trial, with fruit stored in 0.4% O_2 still showing the lowest incidence (15%). In 1% O_2, 80% of fruits were affected, and where fruit had been held in 0.2% O_2 for the first two months prior to storage in 1% O_2 this increased to 95%.

Lower oxygen concentrations continue to retard softening compared to 1%, however, fruit stored in these low oxygen regimes is considerably softer than fruit stored in standard ventilated conditions of (9% CO_2, 12% O_2 (9:12)). Flesh firmness of 23,28 and 36 Newtons for fruit stored in 1.0,0.4% O_2 and 9:12 respectively were measured at the last inspection. In the absence of CO_2, other aspects of deterioration in fruit quality (yellowing, skin greasiness) have advanced more slowly at lower oxygen concentrations.

C. Dover, D.S. Johnson and K. Pearson

APRC HALF-YEARLY REPORT - DECEMBER 1991

SP31: Alternative strategies for reducing wastage in stored apple fruits

(A) Effect of late fungicide sprays, fungicide drenching and selective picking on rotting in Cox

In 1991 a factorial trial was carried out at East Malling in orchards (CW109 and TL109) of contrasting disease status. Cankers caused by *Nectria* were particularly prevalent in orchard TL109 (MM106 rootstock) and a high incidence (12%) of rotting (mainly *Nectria*) was recorded in fruit stored in high and low ethylene concentrations in the previous year (see APRC quarterly report for June 1991). The incidence of rotting in fruit from 8 commercial orchards stored in 1990/91 (APRC low-oxygen trial) varied from 2.1% to 18.5% with the lowest level being recorded in fruit from CW109 (M9 rootstock).

A block of trees in each orchard received three sprays of Captan 83 (3.3 Kg ha^{-1}). The first spray was applied in late-July with subsequent applications at three-weekly intervals. At harvest (23rd-25th September) trees were picked either to normal commercial standards, *i.e.* rejecting rotten and badly formed fruit or selectively, *i.e.* discarding all cracked and rotten fruit and those below 'knee-height' (about 0.5m). All fruit was picked into wooden bins, half of which were subsequently drenched in 'Ridomil mbc' (metalaxyl/carbendazim) at 1 Kg $1000l^{-1}$. The 32 bins of fruit (2/treatment combination/orchard) were loaded into a 20-tonne store according to a statistically designed arrangement. The store is being run at 1.25% O_2 (<1% CO_2) at 3.5°C and is scheduled for unloading after February when a quantitative assessment of rotting will be carried out along with an identification of the main causal pathogens.

Crop yield for CW109 and TL109 was estimated at 27 and 16 tonnes ha^{-1} respectively. Selective picking increased the amount of 'dropped' fruit in orchard CW109 from 1.8 to 3 tonnes ha^{-1} which was equivalent to 6.6 and 10.9% of the total yield respectively. No records were taken of the amount of 'dropped' fruit in orchard TL109. The amount of fruit remaining on the tree after selective picking was 29% and 18% of the total crop from CW109 and TL109 respectively. This remaining fruit was picked into boxes and is currently in a 20-tonne store adjacent to that containing the bulk bins. This store is also being run 1.25% O_2 (<1% CO_2) at 3.5°C and will be opened after February.

B) A commercial scale trial to control superficial scald in Bramley by using ethylene removal and low oxygen CA

Trials to measure the effectiveness of ethylene removal and extreme CA conditions in controlling scald on Bramley are being carried out on two commercial farms.

At one farm a commercial ethylene scrubbing unit has been fitted to a nominal 100-ton store which is being run under conventional ventilated conditions of 9% CO_2 and 12% O_2 (9/12). An adjacent store of similar capacity is being run under similar CA conditions but without ethylene removal. The stores were loaded with Bramley apples (MM106) from two orchards

over a 3-day period (16-19th September). Sixteen of the 318 bins in each store received no post-harvest chemical treatment, the remainder were drenched in DPA. Netted samples (mostly undrenched) were placed into bins which could be accessed from the ceiling hatches.

At another farm a similar ethylene scrubbing unit and an activated carbon CO_2 adsorber were fitted to a nominal 80-ton store. This store, which has automated oxygen control, is being run at 5% CO_2 and 1% O_2 (5/1). Bramley apples (MM106) were harvested on the 11th September and pre-cooled prior to loading on the following day. Twenty-four of the 298 bins of fruit received no post-harvest chemical treatment whilst the remainder were drenched in a mixture of DPA and 'Bavistin' (carbendazim). Netted samples (mostly untreated) were placed in a bin which was positioned under the ceiling hatch. Samples of fruit were also taken to the other trial site and placed in the 'control' 9/12 store, *i.e.* not fitted with an ethylene scrubber.

The concentration of ethylene inside the stores has been frequently monitored (approx. weekly). The ethylene scrubbers have maintained levels of less than 0.01ppm and 0.03ppm in the 5/1 and 9/12 stores respectively. In the non-ethylene scrubbed 9/12 store the ethylene concentration had risen to 10ppm by mid-December.

Samples of fruit are being removed from the stores at monthly intervals (commencing December) and examined for the presence of scald and other storage disorders, firmness and colour are also measured. At the first inspection fruit from all stores had softened very little. Bitter pit affected some fruit stored in 9/12 and was slightly worse where ethylene was not removed. Superficial scald was not found on fruit from the December inspection, this is perhaps not surprising even for untreated Bramley in conventional 9/12, as 1991 was not a high risk season. However, it can be expected that scald will appear in subsequent inspections, as scald promoting compounds, analysed in extracts of apple cuticular wax, have increased in fruit from the 9/12 'control' store.

SP31: Alternative strategies for reducing wastage in stored apple fruits

Mr D.S. Johnson and Mr C.J. Dover

(A) Effect of late fungicide sprays, fungicide drenching and selective picking on rotting in Cox

A 20-tonne store containing bins of fruit from the 1991 factorial trial on Cox (East Malling orchards CW109 and TL109) was opened on 17th February 1992 having been maintained at 1.25% O_2 by controlled ventilation (Bishop Oxystat) and at <1% CO_2 by the inclusion of hydrated lime in the storage chamber. Storage temperature was 3.5°C. Bins of fruit came from orchard blocks which either had or had not received three sprays of Captan 83 (3.3 Kg ha^{-1}) between late-July and harvest. Within each block harvesting had been carried out either to normal commercial standards, i.e. rejecting rotten and badly formed fruit, or selectively, i.e. discarding all cracked and rotten fruit and those below 'knee-height', i.e. about 0.5m. Half of the bins were drenched in 'Ridomil mbc' (metalaxyl/carbendazim) at 1 Kg 1000 l^{-1} prior to storage.

The percentage (by weight) of rotten fruit from trees in orchard TL109 and CW109 which were not sprayed with Captan and picked to normal commercial standards, i.e. control treatment, was 7.2% and 3.8% respectively. Drenching in fungicide after harvest reduced the amount of rotting in fruit from TL109 and CW109 to 2.5% and 2.3% respectively. In the absence of drenching, Captan sprays reduced the amount of rotting in fruit from TL109 (5.4%) but not in that from CW109 (4.5%). However, selective picking alone was more effective than drenching of fruit from CW109 (1.2%) and almost as effective as drenching of fruit from TL109 (3.8%). On both plots Captan sprays and selective picking were as effective as fungicide drenching (fruit picked normally) in controlling storage rots. Whilst fungicide drenching in addition to Captan spraying and/or selective picking not surprisingly resulted in the least amount of rotting in fruit from both orchards the possible substitution of other measures for drenching is most relevant to the trial objectives.

Whilst these results suggest that late fungicide sprays and selective picking may provide control of storage rots in the event of the cessation of drenching it should be borne in mind that both orchards were harvested in dry conditions and as a consequence virtually no *Phytophthora* was recorded in stored fruit, the major pathogen being *Botrytis* (both plots) and with significant amounts of *Nectria* and *Monilinia* (TL109 only).

The amount of fruit remaining on the CW109 trees after selective picking was equivalent to 29% of the crop. The incidence of rotting in this fruit (undrenched, no Captan sprays) subsequently stored in boxes under similar conditions as the bulk bins was 6.8%, which compares with 3.8% for entire trees picked to normal commercial standards. Whilst an increased incidence of rotting due to *Phytophthora* might be expected in fruit from the lower limbs of trees it was somewhat surprising that a higher incidence of all the major rots (*Monilinia, Botrytis, Nectria* and *Penicillium*) should occur in these fruits.

(B) A commercial scale trial to control superficial scald in Bramley by using ethylene removal and low oxygen CA

Ethylene removal from commercial stores maintained in conventional ventilated conditions of 9% CO_2 and 12% O_2 (9/12) and in 5% CO_2 and 1% O_2 (5/1), has been compared with 9/12 without ethylene removal ('control' store). In each store a proportion of the bins of fruit did not receive any post-harvest chemical treatment whilst the remainder were drenched in DPA. Netted samples of untreated fruit, which had been placed into bins accessible from the ceiling hatches, were removed at monthly intervals (commencing December) and examined for the presence of superficial scald and other storage disorders; firmness and green colour were also measured. Untreated fruit from two orchards (A, B) were represented in the 9/12 stores, while in the 5/1 store (on another site) samples came from a single orchard (C). Netted samples from C were also stored in the 9/12 control store.

On the 5th May the store operating at 9/12 without ethylene removal was opened and the final netted samples removed. Superficial scald was found on 74%, 32% and 37% of untreated fruit from orchards A, B and C respectively, DPA-treated samples were free of the disorder. When fruit in two stacks of 8 untreated bins from orchards A and B were examined, almost 100% of fruit in samples taken from bins near the middle and at the bottom of the stacks were affected. However, a lower incidence of scald was found in the top bin of each stack. In these bins the incidence of scald on fruit taken from near the bottom of the bin was greater than on fruit from near the top (85% bottom, 60% top from orchard A, 85% bottom, 15% top from orchard B). These data have important implications regarding the monitoring of fruit quality, particularly scald, from samples stored under ceiling hatches.

When grading of the fruit from the 9/12 control store had been completed the low ethylene 9/12 store was opened (12th May). Virtually complete control of scald was achieved on fruit removed from the untreated bins (2 fruit with slight scald out of 240), and only one fruit (out of 320) from the netted samples was slightly affected.

The untreated bins from both these stores were graded separately from the treated bins. Only 25% of the untreated fruit from the 9/12 control store was suitable for the fresh market compared to 75% from the low ethylene 9/12 store, the increase in downgrading in the control store being due mainly to superficial scald. Quality control assessment in the packhouse showed that, when DPA treated fruit from orchards A and B were combined; 42% of fruit reached Blue and 23% Red grade from the control store compared to 54% Blue and 29% Red grade from the low ethylene 9/12 store.

The store maintained at 5/1 with ethylene removal was opened on July 15th. No evidence of scald was found on untreated fruit either those removed from the 24 untreated bins or from netted samples. Thus complete control of scald ex-store had been achieved. Instrumental measurements confirmed the impression that these fruit had matured very little during 10 months storage. Both green colour and flesh firmness were close to harvest values. Fruit stored in a low ethylene atmosphere (9/12 and 5/1) had lost only 3-4 Newtons in firmness compared to 12 Newtons where ethylene was not removed.

The ethylene scrubbers maintained levels of less than 0.01 ppm and 0.05 ppm in the 5/1 and 9/12 stores respectively. In the 9/12 'control' store the ethylene concentration had reached approximately 40 ppm at the end of storage.

APRC HALF-YEARLY REPORT - MARCH 1993

SP31: Alternative strategies for reducing wastage in stored apple

D.S. Johnson and C.J. Dover

(A) Effect of late fungicide sprays, fungicide drenching and selective picking on rotting in Cox

A 20-tonne store containing bins of fruit from the 1992 factorial trial on Cox (East Malling orchards CW109 and TL109) was opened on 1st March, having been maintained at 1.25% O_2 by controlled ventilation (Bishop Oxystat) and at $<1\%$ CO_2 by the inclusion of lime inside the store. Storage temperature was 3.5°C. Bins of fruit came from orchard blocks which either had or had not been sprayed with Captan 83 (3.3 Kg ha^{-1}) on three occasions between late-July and harvest. Within each block harvesting had been carried out either to normal commercial standards, *i.e.* rejecting rotten or badly formed fruit, or selectively, *i.e.* discarding all cracked and rotten fruit and those below 'knee-height', *i.e.* about 0.5 m. Half of the bins were drenched in 'Ridomil mbc' (metalaxyl/carbendazim) at 1 Kg 1000 l^{-1} prior to storage. Plots CW109 and TL109 were harvested on 14th and 15th September respectively and store loading was completed on 16th September.

The percentage (by weight) of rotten fruit from trees in orchards TL109 and CW109 which were not sprayed with Captan and picked to normal commercial standards, *i.e.* control treatment, was 10% and 12.8% respectively. This compares with a wastage level of 7.2% and 3.8% respectively in fruit from those orchards in the previous year. The increased rotting of the 1992 crop of fruit was probably attributable to a higher than average (31%) rainfall during August. It was interesting that fruit from plot CW109 was less susceptible to rotting than those from TL109 in 1991/92 but showed a higher incidence in 1992/93 and casts doubt on the ability to categorise orchards in terms of their disease potential from season to season. Drenching normally harvested fruit in fungicide reduced the incidence of rotting to 4.5% (TL109) and 3.5% (CW109). The use of Captan sprays in place of drenching did not reduce the amount of rotting. Selective harvesting alone reduced the incidence of rotting in fruit from CW109 (8.3%) but had no effect on those from TL109 (10.7%). Contrary to the previous year's results, selective picking in combination with Captan sprays was not as effective as fungicide drenching (fruit picked normally) in controlling storage rots.

The major pathogen of fruit from both plots was again *Botrytis* with significant amounts of *Monilinia*. *Nectria* caused significant wastage in fruit from TL109 only. Harvesting of both plots was carried out in dry conditions and as a result the incidence of *Phytophthora* rots was low.

The overall effect of fungicide drenching was to reduce rotting caused by *Botrytis* and *Monilinia*, and to a lesser extent *Nectria*. Captan sprays reduced the incidence of *Nectria* to a greater extent than drenching, but had no beneficial effects against other pathogens. The main effect of selective picking was to reduce rotting caused by *Botrytis, Monilinia* and, to a lesser extent, *Penicillium*.

The fruit remaining on the tree after selective harvesting was subsequently picked into boxes and stored under similar conditions as the bulk bins. The assessment of rots was not complete at the time of preparation of this report.

(B) Effect of extreme CA conditions on development of superficial scald in Bramley

The 1991/92 trial had successfully demonstrated, on a commercial scale, control of scald using ethylene removal in both conventional ventilated CA conditions of 9% CO_2, 12% O_2 (9/12) and 5% CO_2, 1% O_2 (5/1). The post-harvest application of a chemical antioxidant gives virtually complete control of scald for up to ten months storage. The same level of scald control can be achieved by low ethylene storage in 5/1, without using such chemical treatments, a considerably more expensive regime to operate than 9/12. The cost and complexity would be reduced were adequate control to be provided without the need for ethylene removal. In 1990/91 reducing oxygen below 1% improved scald control, but in the absence of CO_2 fruit softened unacceptably. It is clear that there is further scope for improving scald control without ethylene removal by optimising the levels of CO_2 and O_2. The effect of O_2 and CO_2 on the development of scald and on the maintenance of other aspects of fruit quality is being evaluated in the current trial. Bramley apples harvested on 7th September, from trees on MM106, are being stored in a range of O_2 concentrations (0.4, 0.6, 0.8, 1.0%) and three levels of CO_2 (1.0, 2.5, 5%). No symptoms of scald have been found during preliminary inspections (11th January, 15th February) of fruit stored under these CA conditions. However, in normal ventilated CA (9/12) scald was evident at the first examination and on 15th February 74% of fruit were affected by scald. Analysis of extracts of apple cuticular wax has shown lower levels of the scald precursor alpha-farnesene at lower oxygen concentrations, and at 5% CO_2 compared with 1 or 2.5% CO_2. None of the storage treatments have caused a build-up of ethyl alcohol in the storage cabinets. Inspections of fruit will continue at six week intervals until 2nd August.

APRC HALF-YEARLY REPORT - SEPTEMBER 1993

SP31: Alternative strategies for reducing wastage in stored apple

D.S. Johnson and C.J. Dover

(A) Effect of chlorine drenching on rotting in Cox

On 13th September Cox trees (MM106 rootstock) on two HRI plots (CW106 and TL109) were harvested into wooden bulk bins to normal commercial standards. The bins were left uncovered on a hard-standing overnight. On the following day, 5 bins from each plot were treated with calcium hypochlorite (100/120 ppm) or 0.01% ai metalaxyl/0.05% ai carbendazim. A further 5 bins per plot were drenched with calcium hypochlorite and after draining for about 2 hours were then drenched again with metalaxyl/carbendazim. The control treatment comprised undrenched bins. Treated bins were drenched two at a time with an approximate drenching time of two minutes. The experimental bins were loaded into a 20-tonne store which is being maintained at 1.25% O_2 and $<1\%$ CO_2 at 3.5°C. It is anticipated that the store will be opened in February/March 1994, when a detailed examination of the fruit will be carried out.

(B) Effect of extreme CA conditions on development of superficial scald in Bramley

In 1992/93 Bramley apples were stored in a range of O_2 concentrations (0.4, 0.6, 0.8, 1.0%) at three levels of CO_2 (1.0, 2.5, 5%). The onset of superficial scald was delayed progressively with reducing O_2 concentration. Increasing the CO_2 concentration also delayed the onset of scald, particularly where O_2 was less than 0.8% . As an example of the range of effects, fruit remained free of the disorder for 29, 35, 42, 47 weeks when stored in 5/1, 2.5/0.6, 5/0.6, 2.5/0.4 (%CO_2/%O_2) respectively. Fruit stored in normal ventilated CA (9/12) had developed scald symptoms after 18 weeks, and more than 90% of fruit were affected by 29 weeks.

The retention of flesh firmness was generally improved by reducing O_2 concentration and by increasing CO_2. Fruit stored under low O_2 conditions with CO_2 at 1% were softer than those fruit stored in 9/12, with the exception of those stored in 1/0.4. Fruit from the other storage regimes were generally firmer than those from 9/12.

A skin disorder which is normally associated with exposure to high levels of CO_2, particularly at the beginning of storage, was evident on some fruit. Although the incidence of this disorder increased with increasing CO_2, it affected an average of 3% of fruit stored in low O_2 atmospheres containing only 1%CO_2. This compares with an average of 6 and 15% at 2.5 and 5% CO_2 respectively, and 4% in 9/12. It was also observed that at 5% CO_2 the skin injury was affected greatly by O_2 concentration, the incidence increasing from 8% at 1%O_2 to 24% at 0.4%O_2.

There was some indication that bitter pit was reduced by reducing O_2 and increasing CO_2 though results were variable, however, an average (over all low O_2 treatments) of 5% of fruit were affected compared with 21% of fruit from 9/12.

There was a strong additive effect of O_2 and CO_2 on the development of scald on these fruit, with the combination of 0.4%O_2 and 5%CO_2 resulting in complete control after 47 weeks storage followed by 14 days at 15°C. There are, however, two areas of concern; the occurrence of the skin disorder that was exacerbated by high CO_2 and low O_2, and the increasing risk of anaerobic respiration with consequent ethyl alcohol formation as the O_2 concentration is reduced. Although none of the storage treatments caused a build up of ethyl alcohol in the storage conditions maintained during 1992/93, seasonal and orchard variability is to be expected.

The influence of rate of establishment of both storage atmosphere and temperature, on the incidence of the skin disorder is currently being studied. Further optimisation of O_2 and CO_2 concentration for scald control is also being investigated. Particular emphasis is being placed on determining the O_2 level at which ethyl alcohol accumulates and early indications are that, in contrast to the 1992/93 storage season, anaerobic respiration has been induced at 0.4%O_2.

APRC HALF-YEARLY REPORT - SEPTEMBER 1994

SP31: Alternative strategies for reducing wastage in stored apples

R J Colgan, C J Dover and D S Johnson

Effect of chlorine drenching on rotting

(a) Cox

Cox apples from two orchards at East Malling (CW109 and TL109) were harvested into wooden bulk bins to commercial standards, on 21 September.

Treatments were applied on 22 September, using a 'Hudson' drencher filled with 300 litres of water. Two chlorine cartridges (calcium hypochlorite) were placed into two 'Klorman' dispensers attached to the main feed line from the pump. Water was diverted through the dispensers by closing the gate valve on the main feed line. The concentration of available chlorine and pH was tested using a 'Pooltester' kit. After 10-15 minutes circulation a chlorine concentration of 100-120 ppm and pH value 7.8-8.2 was measured.

Ten bins of apples, five from each orchard, were treated, two at a time with chlorine for a period of two minutes. For each treatment water samples were taken from the drencher after the first two bins had passed through and again after the final bins had been treated. These samples were subsequently plated out in the laboratory to test for the presence of viable micro-organisms. A further measurement of available chlorine and pH was taken at the end of the treatment.

After completion of the chlorine treatment, the drenching unit was emptied and washed out. A further 300 litres of water was added and allowed to charge with chlorine. Once the concentration of chlorine reached 100-120 ppm and pH 7.8, 0.9 litres of a non-ionic wetter (Tripart Minax) was added to give a final concentration of 0.3% v/v. Drenching was carried out as described above. A large quantity of foam was produced immediately after bins of fruit entered the drencher. However, drench efficiency did not appear to decline due to the foaming.

The drencher was thoroughly washed out and filled with 300 litres of water, to which 300 g of Ridomil mbc (0.1% w/v) was added. Five bins from each orchard were drenched with Ridomil mbc for two minutes. The remaining five bins from each orchard were left untreated. After treatment fruit was loaded into a 20-tonne store which will be maintained at 1.25% O_2 <1% CO_2 and 3.5°C. It is anticipated that fruit will be removed for examination during February 1995.

(b) Bramley

On 22 September Bramley MM106 trees from plot DR 144 at East Malling were harvested into wooden bulk bins.

On the following day drenching treatments (chlorine with and without wetter, Ridomil mbc) were applied using the same procedure described for Cox. Fruit is currently being stored in a 'jacketed' air store at 3°C.

(c) **Comice**

On 27 September Comice trees from four East Malling plots (NG 122, NG 134, DF 140 and DG 134) were picked into bulk bins to normal commercial standards.

Treatments were the same as for Cox and Bramley, except Ridomil mbc was replaced with 1.2 litres of Rovral flo in 300 litres of water (0.4% v/v). It was observed that as soon as the first bins of fruit passed through the drencher the Rovral formulation began to flocculate and chemical deposits were noticeable on the fruit surface.

Five bins of fruit were drenched per treatment, each set of five bins consisted of 1 bin from plots NG122, NG134, and DG134 and 2 bins from DF140. Fruit is now in air storage at -1°C.

Optimising CA conditions for the control of superficial scald in Bramley apples

In the 1993/94 season Bramley apples were stored in a range of CO_2 concentrations (3,4 and 5%) and different levels of O_2, adjustable (A), 0.6 and 0.8%, (see APRC report April 1994). The O_2 concentrations had been set initially to 0.4,0.6 and 'A' also to 0.4% but where raised after three weeks as anaerobic respiration had been induced at 0.4% O_2. The O_2 concentration in the 'A' treatments was increased to 1% in order that the alcohol concentration would decline more rapidly, and was later gradually reduced to 0.4%; further alcohol accumulation did not occur until after 9 months storage. Early indications were that the brief period of anaerobic respiration had enhanced softening, however, at the end of storage (11 months) there was little difference between treatments and the average firmness using an 8mm probe was 35 Newtons (initial firmness 43 Newtons).

The above treatments were more effective than 5/1 (5% CO_2, 1% O_2) in controlling scald. After 11 months storage symptoms of the disorder were evident on 49% of fruit from 5/1, compared to 3% from all other regimes except 3/0.8, where 27% of fruit were affected. Fruit were free of scald for 8 months in 5/1 and 3/0.8, and for almost 10 months in the other treatments. Where CO_2 in the storage atmosphere was greater than 3% and O_2 less than 1%, the incidence of external CO_2 injury was greater than at 5/1, where 3% of fruit were affected. Until a strategy for avoiding CO_2 injury can be established, the use of a low O_2, elevated CO_2 regime to control scald in Bramley should be treated with caution.

Factors affecting the susceptibility of Bramley apples to 'CO_2 injury'

It was clear from the experiences of the 1993/94 storage season that there was considerable variation in the susceptibility to CO_2 injury of Bramley apples from different orchards .

To investigate this variability and to determine the effect of different storage atmosphere establishment procedures on the development of CO_2 injury, fruit from six orchards (four in Kent and two in East Anglia) were harvested on 7 September 1994. These fruit were loaded into storage cabinets, cooled from 15 to 4°C in 5 days simulating typical commercial cooling, and were subject to CO_2 treatments of 5,10 or 20% (in 1% O_2) for 20 days applied at different times, 0,5,10,15 and 20 days from loading. Prior to CA establishment by nitrogen and carbon dioxide injection an atmosphere of air was maintained in the cabinets and, after

treatment, the CA conditions were altered immediately to 5% CO_2 1% O_2. To assess the protective effect of a post-harvest antioxidant, DPA-treated fruit was subjected to the most extreme CO_2 treatment, i.e. 20% CO_2 and 1% O_2. An initial examination of fruit will be made in October primarily to assess skin injury. Further inspections will take place to determine scald development and quality.

SP96: Investigation of the optimum harvest date of 'Gala' apples

P M Genge and J R Stow

An experiment was devised to investigate the optimum stage of maturity at harvest to acheive the best eating quality in fruit stored until February. With the help of Roger Worraker, three 'Royal Gala' orchards of similar age were chosen for the study, two of which are adjacent to plantings of 'Mondial Gala'.

Fruit was picked on three occasions (15th September, 26th September and 6th October) and is now in store at 3.5°C in 2% O_2 and $<1\%CO_2$. Samples will be removed at monthly intervals until February for quality assessment which will include acid, sugar and firmness measurement. Aroma volatile production will be measured and samples will be given to a sensory panel.

At each picking date, samples of both 'Royal' and 'Mondial Gala' were taken for measurement of maturity (plus one sample of 'Gala Must').

It seems that 'Mondial Gala' matures slightly in advance of 'Royal Gala', but there was considerable tree to tree and site to site variation in terms of both maturity and quality.

ALTERNATIVE STRATEGIES FOR REDUCING WASTAGE IN STORED APPLES

APRC Project No. SP31 Report for 6 months ending 31 March 1995

Factors affecting the susceptibility of Bramley apples to 'CO_2 injury'

Previous evidence indicates a close association between the rate of establishment of both storage atmosphere and temperature and the incidence of 'CO_2 injury', slow cooling combined with rapid increase in CO_2 being the most damaging. However, in two trials where Bramley apples were either fast or slow cooled with 9% CO_2 established at five different rates, and where 5/1 (5% CO_2, 1% O_2) was established at various times during slow cooling, the consignments of fruit were 'resistant' to 'CO_2 injury' (see report March 1994). The incidence of this disorder on fruit in several commercial stores during the 1993/94 storage season suggested that there was considerable variation in susceptibility of Bramley apples from different orchards.

In order to develop a strategy for avoiding 'CO_2 injury' the response of susceptible fruit, to various CO_2 treatments and delays in CA establishment, is being studied. In September 1994 fruit from six orchards (four in Kent and two in East Anglia) were cooled at a typical commercial rate and were subject to CO_2 treatments of 5, 10 or 20% (in 1% O_2) for 20 days applied at 0, 5, 10, 15 and 20 days from loading (see report September 1994).

All fruit were inspected externally 14 days after the end of the CO_2 treatment, sub-samples were inspected later for internal injury. The incidence of both external and internal injury was reduced by delayed application of CO_2 treatment and by decreased CO_2 concentration. A considerable range in susceptibility to external injury was found between fruit from the different sites, e.g. 0-39% of fruit were affected externally when 5/1 was established on day 0, 3-53% when 20/1 was applied on day 15. In general, the incidence of internal injury was less than that for the external disorder and fruit from those sources that had the highest incidence of external injury were the most susceptible to internal injury.

Where the establishment of 5/1 was delayed for 10 days fruit from five of the six sites were affected externally (2-9%). In order to avoid external symptoms on any fruit it was necessary to delay the establishment of 5/1 for 15 days. Treatment with DPA gave complete protection against external CO_2 injury and injury to the mid and outer cortex, and slightly reduced injury to the inner cortex. When fruit were inspected at the end of March 1995 there was insufficient scald present (four fruit with very slight symptoms from over 3,000 examined) for any treatment effects to be determined. To follow scald development inspections will continue until the end of June, when the effect of treatments on other quality attributes will also be assessed.

Effect of chlorine drenching on rot development in Cox and Bramley apples and Comice pears

Chlorine (calcium hypochlorite) drenched Cox and Bramley apples and Comice pears were removed from store between 22nd January and 1st February 1995. Experimental bulk bins were individually graded, all rots were removed, weighed, counted and identified.

Results for CA-stored Cox indicate that drenching in 100ppm (pH 7.8-8.2) chlorine is not as effective as a standard Ridomil-mbc (metalaxyl/carbendazim) treatment. The level of rotting in undrenched fruit from orchards CW109 and TL109 was 3.8% and 11.2% respectively. Ridomil-mbc reduced the incidence of rotting to 1.4% (CW109) and 7.5% (TL109). Whilst chlorine reduced the overall level of rotting in fruit from TL109 (8.9%), where the incidence of *Botrytis cinerea* and *Nectria galligena* were of equal importance, it increased rotting in fruit from CW109 (4.5%), where *Botrytis* was the predominant pathogen. These results support those obtained in the previous year (see APRC report for April 1994). The addition of a non-ionic wetter did not reduce further the level of rotting compared to chlorine alone.

The control of post-harvest rotting in air-stored (-0.5 to -1°C) Comice by post-harvest treatments was generally more successful than with Cox, Rovral-flo (iprodione) and chlorine with or without wetter reduced rotting by half that found in undrenched controls (3%). Chlorine reduced rotting in Bramley by about 60% of the level of undrenched controls (18%). Although the addition of a wetter slightly enhanced chlorine efficacy, Ridomil-mbc proved the most effective treatment. The high incidence of rotting was associated with prolonged storage in air at 3°C and poor fruit mineral composition which enhanced both senescent breakdown and rot development. More detailed analysis of these data is currently in progress.

In order to determine the degree to which chlorine reduced the number of viable pathogenic spores present in the drench tank, samples of drench water were taken at intervals during the treatment and subsequently plated out.

In the Cox, Bramley and Comice trials, drenching with chlorine at 100 ppm (pH 7.8-8.2) with or without the addition of a wetter was effective in killing all fungal spores, bacteria and yeast cells in the drench water. However, with fungicide treatments a build-up in spore numbers occurred as drenching progressed. After treating two bins of Bramley apples with Ridomil-mbc the drench solution contained 11 spores/ml, the spore concentration increased after five bins had been treated to 41 spores/ml, due to an increase in *Mucor* spores. Initial samples of drench water from Cox treated with Ridomil-mbc contained 7 spores/ml and increased to 66 spores/ml after 10 bins, caused by an increase in *Penicillium* and *Mucor* spores.

Similarly, after treating two bins of Comice pears with Rovral-flo the drench water contained 34 spores/ml of *Mucor* and *Penicillium*, this increased to 51 spores/ml after drenching five bins, due to a rise in *Penicillium* spores. These results confirm the need to replace regularly the solution in the drench tank as recommended.

Spore traps were placed in a 20-tonne CA Cox store and two 'jacketed' air stores one containing pears at -0.5 to -1°C, the other with mixed apple varieties, including Bramley's at 3.0°C. Traps were set at monthly intervals to monitor the presence of airborne spores throughout the storage period. Petri dishes containing PDA amended with Streptomycin sulphate were exposed to store atmospheres for 10 minutes and then incubated for 3 days at 21°C.

Penicillium spores were predominant in the air circulating around each store. However, *Cladosporium* spores were also present in significant numbers in the Cox store. The number of airborne spores did not increase during the storage period although spore numbers were effected by the intermittent action of the store circulation fan. Monitoring airborne spores in apple and pear stores merits future investigation since this may be relevant to the development of secondary rotting.

D S Johnson, C J Dover and R Colgan

APRC 6-monthly report March 1996

SP31 Alternative strategies for reducing wastage in stored apples

Effect of late season captan sprays, selective harvesting practices and chlorine drenching on control of rots in Cox's Orange Pippin apples

The fruit from this trial was removed from CA store on the 19 February 1996. All fruit was graded to commercial standards and all rots were removed, counted and identified. As in previous years, there was a difference in the amount of rotting that developed in fruit from the two orchards used for the study. Rot incidence, averaged over all treatments, was 6.8% in TL109 fruit compared with only 1.2% in that from orchard CW109. Brown rot was the predominant pathogen in fruit from both orchards but was nearly 5 times more prevalent in that from TL109. There was also a significant amount of rotting due to *Nectria, Botrytis* and *Phytophthora* with higher incidences associated with TL109.

Fruit from TL109 and CW109 which had received no pre-harvest captan sprays or post-harvest chlorine treatment and had been picked to normal commercial standards developed 9.6% and 2.3% rotting respectively. Captan sprays reduced rot incidence to 6.6% and 0.8% respectively mainly by reducing *Phytophthora, Botrytis* and Brown rot. Selective harvesting reduced the incidence of rotting in fruit from CW109 from 2.3% to 1.2% and was attributed to a reduction in *Phytophthora* and Brown rot. Moreover selective harvesting in combination with captan application reduced further the amount of rotting to 0.8%. In the TL109 orchard selective harvesting alone did not reduce rotting compared with normal harvesting but, when combined with captan spraying, rotting was reduced from 6.6% to 3.4% due mainly to a reduction in *Nectria* and Brown rot. Chlorine alone was generally ineffective in controlling rotting in fruit from both orchards. However, fruit from trees in orchard TL109 which had received captan sprays and were then drenched in chlorine developed 4.3% rotting compared with 6.6% in undrenched, captan-sprayed fruit. Similarly in fruit from CW109 chlorine drenching only reduced rotting in fruit picked from captan sprayed plots. Chlorine applied to captan-sprayed, selectively-harvested fruit reduced rotting from 0.8% to 0.3%.

Further work is in progress to determine the statistical significance of the treatment differences in the amount of rotting that was recorded.

Biological control of rotting in Cox

Fruit from this trial was removed from CA storage on the 23 February. All apples were graded to a commercial standard and all rots were removed, weighed and identified as before. In general there was a low level of rotting in all treatments, the predominant pathogen being Brown rot although *Botrytis* rots were also present. Aspire, a commercial preparation of the yeast *Candida oleophila,* slightly reduced the overall level of rotting from 1.6% (undrenched controls) to 1.3%. The most effective treatment was metalaxyl/carbendazim which reduced the incidence of rotting to 1%. Aspire combined with a 1/10 dose rate of carbendazim resulted in a similar amount of rotting as in the undrenched fruit. A pre-drench in chlorine prior to treatment with Aspire did not improve the degree of rot control compared to Aspire alone. It was unfortunate that the orchard selected for the trial did not produce fruit with a higher susceptibility to rotting.

Chlorine Drenching of Conference Pears

Twenty bins of Conference pears were removed from a 'jacketed' air store (-1°C) in the Jim Mount Building on the 5 February. The bins were unloaded by hand and rotten fruit was removed. Healthy and diseased fruit from each bin was weighed and numbers of rotten fruit were recorded and type of rot identified. In addition, any 'nests' of *Botrytis* rots were examined and the number of primary and secondary rots was recorded. The major pathogen was *Botrytis* with fewer occurances of Brown rot and *Penicillium Spp*. Chlorine drenching, with or without added wetter, was ineffective in controlling storage rots whereas iprodione reduced rotting from 3% to 1%.

Chlorine Drenching of Bramley Apples

Twenty bulk bins of Bramley apples were removed from a commercial CA store (9% CO_2, 12% O_2 at 4°C) on the 11 March. Fruit was graded by hand and all the rots were removed. The predominant pathogen in all treatments was *Penicillium* but substantial numbers of *Phytophthora* and Brown rots were also recorded. The incidence of rotting in chlorine and fungicide-treated (metalaxyl/carbendazim) fruit was 3.4% and 3.3% respectively and was similar to the level in fruits treated with DPA only (3.2%). Fungicide application reduced the incidence of *Phytophthora* and Brown rot although it failed to reduce *Penicillium* rots. Drenching Bramleys in chlorine with added wetter significantly increased the amount of rotting and of *Penicillium* in particular. The high level of rotting in all treatments attributed to *Penicillium* may be in part due to the low level of calcium present in the fruit.

Avoiding CO_2 injury while maintaining control of superficial scald in Bramley apples stored in 'extreme' CA conditions

The response of Bramley apples to delayed establishment of product generated CA, as a strategy for avoiding CO_2 injury, is being investigated. Fruit from the same sites used in the 1994/95 trial was placed in storage containers that were either sealed on loading or after 5, 10, or 15 days and a controlled atmosphere of 5/1 (5% CO_2, 1% O_2) was established by fruit respiration only. Prior to sealing an atmosphere of air was maintained in the cabinets and, after 20 days from sealing, the O_2 concentration was allowed to further reduce to 0.8, 0.6 or 0.4% with some cabinets continuing at 1%, the concentration of CO_2 was maintained at 5% throughout. To compare the susceptibility to CO_2 injury of this fruit with that from last season, samples of fruit were subjected to 10% CO_2 ,1% O_2 (10/1) generated at time of loading and maintained for 20 days (a treatment used in the 1994/95 trial that resulted in a high incidence of injury).

An initial examination of fruit made in October to assess skin injury and a more detailed inspection in December indicated a greatly reduced susceptibility to 'CO_2 injury' in fruit from the 1995 harvest. On average 12% of fruit stored in 10/1 had symptoms of external 'CO_2 injury' in 1995 compared with 52% in 1994. As the sealing of storage containers was delayed the incidence of the disorder was reduced from 3.2% (no delay) to 0.2% (10 days) and eliminated where the delay was 15 days. When fruit was inspected for the development of superficial scald in early March, it was found that the incidence increased dramatically with delay in CA establishment, eg. 0, 1, 14 and 67% of fruit affected for delays of 0, 5, 10 and 15 days respectively, where fruit was stored in 5/1. However scald incidence was reduced

by storage in lower O_2 concentrations, so that despite a 15 day delay in sealing, only 16% of fruits were affected by scald when stored in 0.6% O_2 and no symptoms were found for shorter delays. Further inspections will take place at six week intervals to monitor treatment effects on scald development and other quality attributes will be assessed at the end of storage.

SP96 Storage of Gala: Investigation of alternative conditions

This project is the second in a three-year programme which has the objective of determining for Gala the optimum picking date, optimum storage conditions and maximum storage life. The first trial, in 1994/5, investigated the effect of picking date on Gala stored under conditions known to have a low risk of disorders (2% O_2, <1% CO_2 at 3.5^{0}C). The current trial is attempting to determine the optimum storage conditions. Fruit, harvested at the correct stage of maturity, is being stored in a total of 17 conditions. Scrubbed CA treatments include CO_2 levels of 0, 2.5 and 5% and O_2 levels of 1, 1.5 and 2%. In addition ventilated CA conditions of 8% CO_2 (13% O_2) and air storage are included. All treatments are represented at 1.5^{0}C with a reduced number of conditions (0/1, 0/2, 5/1, 5/2, and 8/13-CO_2/O_2) at 3.5^{0}C plus storage in air at 0^{0}C. Inspections have so far been carried out in December, January and February, with the last scheduled for mid April.

In fruit stored until February the incidence of disorders has been low and differences between treatments only appear in fruit quality. As the length of storage increases, so the conditions required to maintain fruit firmness become more stringent. In scrubbed low oxygen storage higher carbon dioxide (up to 5%) was associated with highest firmness retention. Lower oxygen (down to 1%) during storage was associated with greatest retention of firmness during a simulated marketing period of 7 days at 20^{0}C. Thus 5% CO_2 + 1% O_2 at 1.5^{0}C was overall the condition giving the firmest fruit.

As in 1994/5, flavour volatile production declined dramatically after December, in all storage conditions. Sensory panel acceptability scores also declined after December. A preliminary analysis of the sensory panel data suggests that panelists based their scores on their perception of the firmness of the fruit, rather than on their perception of the flavour. There was a poor correlation between instrumental and sensory firmness measurements.

SP31 Alternative strategies for reducing wastage in stored apples

(A) Effect of late season captan sprays and selective harvesting on control of post-harvest rotting in stored Cox's Orange Pippin apples.

Following the success of last year's trial with late season captan sprays and selective harvesting as an alternative strategy to post-harvest fungicide drenching of Cox, a further trial was conducted in six commercial orchards, each with a different rot profile encompassing a range of post-harvest diseases.

Each orchard received a standard fungicide spray programme throughout the season but, in addition, selected rows of trees were sprayed with captan 80 at a rate of 2.7 kg ha^{-1}, at the beginning of August, with further sprays in late August and again 7-10 days before harvest. The exact timing of the second and third sprays varied between orchards due to the difference in anticipated harvest dates.

At harvest selected groups of trees from sprayed and unsprayed sectors in each orchard were picked either to normal commercial standards or selectively harvested, whereby fruits below 0.5 m from the ground were omitted from the storage bins along with diseased, cracked and insect-damaged fruits. Four bins per treatment were placed into commercial CA storage.

None of the 16 bins of experimental fruit per orchard received post-harvest fungicide treatments. It is anticipated that fruit will come out of store some time between mid-December and mid-February.

During the growing season Dr Angela Berrie carried out a rot risk assessment on each orchard and this information will be used to compare estimated rot levels with the actual amount removed from the bins at grading.

Results of this research were discussed with other scientists via a poster presentation at the Brighton Conference and in a paper given at the IOBC 4th workshop on Integrated Control of Pome Fruit Diseases held in the UK during August 1996.

(B) Avoiding CO_2 injury while maintaining control of superficial scald in Bramley apples stored in 'extreme' CA conditions.

The effect of delayed establishment of product generated CA on the incidence of CO_2 injury in Bramley apples was described in the last report (March 96), and indicated that it may be necessary to delay sealing the store for up to 10 days to control CO_2 injury. An initial assessment of treatment effects on scald control was given also. The monitoring of scald development has continued and the measurements of other fruit quality attributes were carried out at the end of storage.

Fruit had been placed in storage cabinets that were either sealed on loading or after 5, 10, or 15 days and a controlled atmosphere of 5/1 (5% CO_2 , 1% O_2) was established by fruit respiration only. Prior to sealing, a cabinet atmosphere of air was maintained and, after 20 days from sealing, the O_2 concentration was allowed to further reduce to 0.8, 0.6 or 0.4%, with some cabinets continuing at 1%. The concentration of CO_2 was maintained at 5%.

The incidence of superficial scald increased considerably with delay in sealing the storage cabinets. However the onset of scald symptoms was delayed and incidence reduced by storage in O_2 concentrations below 1%, eg. symptoms of scald were first observed after 26, 32 and 44 weeks storage for O_2 concentrations of 0.8, 0.6, 0.4% respectively, where cabinet sealing was delayed for 10 days. Where the delay in sealing was less than 10 days, scald did not appear on fruit stored in 5/0.4, until they had been subjected to a "shelf life" of 14 days at 18 °C at the end of storage (44 weeks). Fruit softening and yellowing were generally increased by a delay in sealing and by higher O_2 concentrations, though fruit quality remained commercially acceptable except for fruit stored in 5/1 with a 15 day delay. As sealing was delayed the incidence of bitter pit increased from an average of 0.6 to 11% for 0 and 15 days delay respectively and, contrary to previous findings, lowering the O_2 concentration did not reduce the proportion of fruit affected. Ethyl alcohol and acetate levels were very low even where fruit was stored in 0.4% O_2.

It is clear that delaying the establishment of 'extreme' CA conditions can greatly reduce the incidence of CO_2 injury. The delay time is determined by seeking a compromise between the requirements to control this disorder and to maintain control of superficial scald, as it is the appearance of scald symptoms rather than the decline in other quality attributes that limits storage as the delay is increased. This year delays in atmosphere establishment are being evaluated using Bramley apples from 15 orchards in Kent and East Anglia (including four of the orchards used in previous years). Fruit were cooled from ambient (16.5°C) to 4°C in 5 days to simulate a typical commercial rate. Storage container atmospheres of 5/1 were either product-generated (by fruit respiration only) or flushed (by the injection of N_2 and CO_2). Cabinet sealing was delayed for 5 or 10 days from loading where CA was product generated and for 10 or 15 days for flushed CA. An additional flushed treatment was applied, where 1% O_2 was established 5 days from loading and CO_2 was maintained below 1% for a further 10 days and then increased to 5% by injection.

To compare the susceptibility to CO_2 injury of fruit in 1996 with that from previous seasons, samples of fruit were subjected to 10% CO_2, 1% O_2 (10/1) generated at time of loading and maintained for 20 days (a treatment that has been used to produce a relatively high incidence of injury). An examination of this fruit has shown that susceptibility to CO_2 injury is high this season and, where the 4 orchards used previously were averaged, 60% of fruit were affected by external injury compared to 12 and 40% in '95 and '94 respectively. A detailed assessment of CO_2 injury on fruit from the other treatments will be made at the end of November. Further inspections will take place to monitor scald development and other aspects of quality will be assessed at the end of storage.

Results of APRC-funded work on CO_2-injury and scald development were included in a paper presented at an international postharvest conference held in Taupo, New Zealand from 4-9th August 1996.

APRC Project Report

Project SP31: Strategies for reducing wastage in stored apples and pears

Project Staff: Richard Colgan, David Johnson and Colin Dover

Date: Report to 31 December 1997 (final)

Avoiding CO_2- injury while controlling superficial scald in Bramley apples stored in 'extreme' CA conditions.

In 1996/97 a trial was conducted to develop a strategy to reduce the incidence of CO_2 -injury in Bramley apples stored in 5% CO_2 and 1% O_2 (5/1), while maximizing the length of time fruit could be stored without the development of scald. A comparison was made between the methods of establishing storage atmospheres (5/1) either by fruit respiration (product-generated CA), or by the injection of N_2 and CO_2 (flushed CA). The effects of delays in establishing CA conditions on CO_2-injury and scald were investigated. Where CA (5/1) conditions were established by respiration, sealing of the containers was delayed by 5 or 10 days. Where CA conditions were established by flushing, the delay to establishment was 10 or 15 days.

Results of these treatments on the incidence of CO_2-injury were reported to APRC in the six-monthly report for September 1996 - March 1997. During the post-March period, further inspections were made to monitor the development of scald. Symptoms of scald first appeared on apples examined at the beginning of April (Table 1). The average incidence of scald in fruit from product-generated stores subjected to a 5 and 10-day establishment delay was 0.45% and 2.2% respectively. Delaying the establishment of product-generated conditions by 10 days prevented CO_2-injury and provided control of scald until the recommended termination date of March.

Where CA had been established by flushing, scald did not occur until May. Delaying the establishment of CA from 10 to 15 days increased the incidence of scald from 0.7 % to 7.1 %. Reducing the concentration of oxygen after 5 days and adding 5% CO_2 after 15 days did not reduce scald significantly compared to other flushed treatments. At the final inspection at the beginning of July, the incidence of scald had increased markedly in all treatments. Establishment of CA by flushing may be preferred in order to achieve maximum control of scald although this must be delayed by 15 days from cooling in order to prevent CO_2-injury.

The variation in the incidence of scald (Table 1) between consignments of fruits emphasises the need to provide a robust control strategy which can be used by all Bramley growers. Delaying product-generated 5/1 atmospheres by 10 days eliminated the incidence of CO_2-injury and provided control of scald to the end of March. Previous research has found that control of scald can be extended beyond March if the concentration of oxygen is reduced from 1% to 0.8%. Further work is required to identify the most effective combination of oxygen and carbon dioxide.

Table 1. Effect of rate of establishment of CA on the incidence (%) of scald on Bramley's Seedling apples stored in 5% CO_2 and 1% O_2 at 4°C.

	Product day 5	Product day 10	Flushed day 10	Flushed day 15	Flushed day 5/15
% Scald: April					
Mean	0.45	2.24	0	0	0
Maximum	3.5	11.8	0	0	0
Minimum	0	0	0	0	0
% Scald: May					
Mean	6.7	19.1	0.7	7.1	3.6
Maximum	22.1	43.3	3.3	25	7
Minimum	0	6.7	0	0	0
% Scald: July					
Mean	38.9	57.3	27.5	50.0	28.1
Maximum	78.6	88.3	67.0	82.9	55.8
Minimum	6.7	33.3	5.1	10.0	11.8

Data are means for 15 commercial orchards harvested on 12 September 1996.

All fruit were cooled within 24 hours from loading.

Product day 5 - Storage cabinets sealed 5 days from loading
Product day 10 - Storage cabinets sealed 10 days from loading
Flushed day 10 - Storage cabinets flushed with N_2 and CO_2 10 days after loading
Flushed day 15 - Storage cabinets flushed with N_2 and CO_2 15 days after loading
Flushed day 5/15 - Storage cabinets flushed with N_2 after 5 days and CO_2 15 days after loading (<1% CO_2 between day 5 and day 15)