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Contents

Grower Summary

Headline

Improve the quality of Gala apples from controlled atmosphere storage by reducing the storage temperature.

Summary of results and main conclusions

The quality of Gala apples stored in controlled atmosphere (CA) conditions at the recommended temperature (1.5-2^{o}C) was compared with that of fruit stored at the lower temperature (0-0.5^{o}C) currently recommended for air storage. Mondial Gala apples from six orchards in 2000 and two orchards in 2001 and 2002 were stored in four CA regimes treatments (CO_2/ O_2): 5/1, <1/1, <1/2 and 8/13, and at two storage temperatures: 1.5-2^{o}C and 0-0.5^{o}C. In the latter two years fruit was harvested on three occasions over a two-week period.

The main results of the three-year study can be summarised as follows:

- Reducing the storage temperature reduced softening of fruit stored in all CA conditions both immediately ex-store and after a simulated marketing period (SMP) of seven days at 20^{o}C. This was particularly important for fruits stored in the 8/13 regime that tended to soften rapidly during the SMP.
- Acidity was higher in fruit stored at the lower temperature and although soluble solids levels were lower in fruit stored at the lower temperature during the early period of storage they eventually exceeded those of fruit at the higher temperature.
- There were no effects of storage temperature on background colour, greasiness or the incidence of rotting. These characteristics were influenced primarily by the date of harvest and to a lesser extent by the different CA conditions. Delay in harvesting resulted in yellowing of the background colour and promoted greasiness of the skin of the fruits and in one year increased the incidence of rotting.
- There were no adverse effects of the lower storage temperature on fruit stored in the 8/13, <1/2 and <1/1 CA regimes for the prescribed periods i.e. early November, early January and mid February respectively. Over-storing in any particular regime will lead to the development of core flush and flesh breakdown, particularly in fruit stored in the 8/13 regime. Storage at the lower temperature will exacerbate the problem of flesh breakdown where fruit is over-stored.
- In 5/1 the increased incidences of core flush and breakdown that resulted from storage at the lower temperature (0-0.5^{o}C) dictates that no change is made to the recommended temperature (1.5-2^{o}C) specifically for this CA regime.
- Picking date had a marked effect on the storage quality of apples stored in all CA regimes but particularly 5/1. Only the earliest picked fruit in 2001 and 2002 stored until April without the development of internal disorders during a SMP. Fruit suitable for long-term storage in 5/1 had a starch coverage of 78-88% at harvest.

- Although fruit picked at an advanced stage of maturity i.e. starch coverage as low as 40% did not develop physiological disorders in the 8/13, <1/2 and <1/1 CA regimes, such fruit was often greasy and was susceptible to water core. Results indicate that harvesting when starch coverage is about 85% will avoid these problems.
- Fruit from six sites in East Anglia and Kent picked on the same calendar date in 2000 stored well in all CA conditions. The average starch coverage was 83% which fits in well with the results of the picking date study done in subsequent years. Combining all the results suggests that a starch coverage of 80-85% is necessary to achieve optimum fruit quality in all types of CA. It is fortuitous that in tests run by the Quality Fruit Group the best eating quality ex-store was associated with starch coverage in excess of 80%.

Action points for growers

1. Pick fruit intended for storage when the starch level (% black showing in the starch/iodine maturity test) has declined to 80-85%.
2. Maintain a storage temperature of 0-0.5°C for fruit stored in CA regimes of 8/13, <1/2 and <1/1 (CO_2/ O_2).
3. Maintain a storage temperature of 1.5-2°C for fruit stored in the 5/1 (CO_2/ O_2) CA regime.
4. Observe the maximum duration stipulated for each type of CA condition i.e. early November, early January, mid February and early April for 8/13, <1/2, <1/1 and 5/1 respectively.
5. Monitor the condition of the fruit every month both immediately ex-store and after a further 7 days at 18-20°C.

Storage recommendations for Gala (all clones)

Controlled atmosphere (CA)							
No scrubber				Using a scrubber			
Temperature		% CO_2	Terminate	% CO_2	% O_2	Terminate	Notes
°C	°F						
0-0.5	32-33	8	Early Nov	<1	2	Early Jan	1
0-0.5	32-33			<1	1	Mid Feb	2
1.5-2.0	35-36			5	1	Early April	2, 3, 4

Air storage of Gala at 0-0.5°C (32-33°F) should be terminated by the middle of December

Notes:

1. Ensure that O_2 level does not fall below 1.7% when controlling manually at 2% O_2, aim to keep a mean of 2%
2. For operation at 1% O_2 use automatic equipment to control O_2 within the range 0.9-1.1%
3. Ensure that the recommended CO_2 level is not exceeded by more than 0.5%
4. Avoid late picking

Science Section

Background and objectives

Whilst there is general acceptance of the controlled atmosphere (CA) recommendations for Gala that were published in APRC News (Issue 21) it is clear from recent information presented by the Gala Club (Gala News No. 18) that the cultivar is often allocated 'second best' conditions. The view that ventilated CA conditions of 8% CO_2 + 13% O_2 (8/13) are perfectly adequate for Gala contradicts the results of earlier research funded by APRC and those obtained by other technical groups within the industry. Limitations of the 8/13 regime were discussed in the article in the APRC News 27 issued in August 2001. Although the major objective of the work was to investigate the prospect of reducing the storage temperature for CA-stored Gala apples the effects on storage quality of a range of CA conditions, including 8/13, were evaluated. In order to provide robust storage recommendations it was necessary to include fruit from different orchards and to investigate the effects of harvest date. Ideally experience should be gained over several years before minimum storage temperatures are established for any cultivar of apple. Seasonal variations in climatic factors affect the susceptibility of apples to disorders such as core flush and low temperature breakdown that are also influenced by storage temperature. However, in the case of Gala, the current research was concerned with the fine-tuning of storage temperature that follows on from the earlier work (1994-97) funded by APRC (project SP96) to establish broad parameters for storage (see also issues 21 and 27 of APRC News).

This 3-year project began in July 2000 and was concluded in June 2003. Project reports were provided to APRC (and more recently to HDC) every 6 months. This final report is a synthesis of the information contained in the series of progress reports.

Materials & Methods

Year 1 (2000/01)

On 20 and 21 September 2000 samples of apples were taken from six commercial 'Mondial' Gala orchards in Kent (4) and East Anglia (2) and transported immediately to HRI-East Malling. At this time commercial harvesting was underway or imminent. On arrival at East Malling sub-samples of fruit were taken for maturity assessment and for mineral analysis. The remaining fruit from each orchard was allocated to small-scale (90-kg) CA chambers. There were four CA storage treatments (CO_2/ O_2): 5/1, <1/1, <1/2 and 8/13, and two storage temperatures: 1.5-2^oC and 0-0.5^oC. There were two replicate chambers for each storage treatment. Samples of fruit were removed from store after 55, 106, 153 and 178 days. These were assessed for the presence of physiological disorders. Measurements of firmness were carried out using an automated penetrometer fitted with an 11-mm probe. Juice was extracted from each sample for measurement of soluble solids and acid concentration. Assessment for disorders and measurement of firmness were repeated on fruit subjected to a

simulated marketing period of seven days at 20ºC. Detailed descriptions of the methods used are described in the annexe to the report.

Year 2 (2001/02)

On 24 September and 1 and 8 October 2001 samples of apples were taken from two commercial 'Mondial' Gala orchards in Kent and transported immediately to HRI-East Malling. These orchards, referred to as P and W in the tables of results, were used in the previous year. On arrival at East Malling sub-samples of fruit were taken for maturity assessment. The remaining fruit from each orchard was allocated to small-scale (90-kg) CA chambers. There were four CA storage treatments (CO_2 / O_2): 5/1, <1/1, <1/2 and 8/13, and two storage temperatures: 1.5-2ºC and 0-0.5ºC. There were two replicate chambers for each storage treatment. Samples of fruit were removed from store (8/13 only) on 5 November 2001. In 2002 further removals were made on 15/16 January (8/13 and <1/2), 13-15 February (8/13, <1/2 and <1/1) and 10-16 April (8/13, <1/2, <1/1 and 5/1). On removal from store fruit samples were examined for the presence of physiological disorders and an assessment made of background colour and greasiness. Measurements of firmness were carried out using an LRX materials-testing machine fitted with an 11-mm probe. The fruits were then cut and examined for the presence of internal physiological disorders. Measurements of firmness and assessments for disorders were repeated on fruit subjected to a simulated marketing period (SMP) of seven days at 20ºC. Detailed descriptions of the methods used are described in the annexe to the report.

Year 3 (2002/03)

The experiment carried out in 2002 was essentially a repeat of that carried out in 2001 although picking commenced a week earlier in 2002 in recognition of an early season and dates of removal of fruit from store differed slightly in the two years. Harvest dates in 2002 were 17 and 24 September and 1 October. Samples of fruit were removed from store on 6 November (8/13), 15/16 January (8/13 and <1/2), 12-14 February (8/13, <1/2 and <1/1) and 7-10 April (8/13, <1/2, <1/1 and 5/1).

Results and Discussion

Year 1 (2000/2001)

Harvest maturity

The more practical measures of harvest maturity are firmness, soluble solids (sugar) content and the extent of starch conversion. No precise guidelines have been developed to indicate optimum harvest maturity in relation to storage. Previous work suggested that Gala stored well when picked at above 7 kg (70 N) firmness and over a broad range of starch levels (50-90% black). In comparison with these criteria the apples from the orchards in the study were very firm with high levels of starch (average Ctifl score of 3.8). A Ctifl score of 4 is equivalent to about 82% starch cover. However, increase in ethylene production is the physiological marker of ripening. Internal ethylene concentration (IEC) in excess of 100 ppb normally indicates that a fruit has commenced its ripening and fruits for storage are usually picked just prior to this event. The IEC data in Table 1 suggests that a high proportion of fruit in all orchards except East Anglia (L) were already ripening when harvested on 20 or 21 September.

Table 1. **Harvest maturity data** for 6 commercial 'Mondial' Gala orchards used in the 2000/01 storage experiment. Starch scores relate to the Ctifl starch conversion chart where 1 is almost completely black (100% starch cover) and 10 is almost completely white (0% starch cover). IEC is the concentration of ethylene in the core cavity of the fruit. Firmness and soluble solids were measured with an automated penetrometer and a refractometer respectively, and acidity by titration.

Orchard ref.	Firmness (N)	Sol. Solids (%)	Starch score (Ctifl)	IEC (% fruits >100 ppb)	Acidity (g/kg)
Kent W	84.9	11.1	3.8	40	3.5
Kent C	83.9	11.9	3.5	40	3.3
Kent P	81.0	11.8	3.7	80	3.6
Kent Pt	76.4	11.6	4.5	50	2.8
E. Ang. W	79.8	11.7	4.2	90	2.8
E. Ang. L	81.2	10.9	3.0	10	3.2

Fruit mineral composition

Mineral composition data confirmed previous findings that Gala is a low nutrient apple as regards nitrogen (N), phosphorus (P) and potassium (K) although it has much higher calcium (Ca) levels than many other dessert apple cultivars (Table 2). No mineral analysis standards have been established that provide for optimum storage quality. This can only be achieved by larger scale survey experiments conducted over many years. It is therefore difficult to know whether there should be concern over concentrations of N, P and K that in Cox would be considered to be critically low and would be expected to give rise to problems with storage quality. In the event of storage disorders developing in samples of fruit from these orchards it will be interesting to note any association with their mineral composition.

Table 2. **Mineral compositions** of 'Mondial' Gala apples at harvest (20/21 September 2000).

Orchard ref.	N	P	K	Ca	Mg
			mg $100g^{-1}$		
Kent W	36.8	8.5	104	9.4	4.7
Kent C	32.7	7.8	102	7.1	4.4
Kent P	50.2	9.8	121	7.4	4.6
Kent Pt	31.4	7.6	95	7.0	4.3
E. Ang. W	43.4	8.9	90	7.5	4.1
E. Ang. L	36.4	8.7	104	7.7	4.6

Orchard ref.	Na	Mn	Zn	Cu	B
	mg $100g^{-1}$			μg $100g^{-1}$	
Kent W	0.38	60	34	33	218
Kent C	0.48	53	30	32	216
Kent P	0.66	61	35	48	213
Kent Pt	0.35	85	35	24	243
E. Ang. W	0.31	52	31	35	398
E. Ang. L	0.74	53	27	27	348

Storage quality

Overall effects of temperature

Removal 1

At the first examination in mid-November (55 days) fruit stored at the lower temperature (0-0.5ºC) were slightly, but significantly, firmer (Table 3). However, there was no significant effect of storage temperature on the firmness of the fruit after a further 7 days at 20ºC (Table 4). Soluble solids content was slightly, but significantly, lower in fruits stored at the lower temperature (Table 5). This may have been anticipated since conversion of starch to sugar during storage is likely to be slowed by the lower rate of metabolism associated with the lower temperature. Acid

concentration was higher in fruit stored at the lower temperature (Table 6). No disorders were evident in the fruit at either temperature (Tables 7-10).

Removal 2

At the second examination of the stored fruit in early January (106 days) there was no significant effect of storage temperature on the firmness of the fruit immediately ex-store (Table 3). However, after a further seven days at 20ºC those fruit that had been stored at the lower temperature were firmer (Table 4). The soluble solids concentrations were similar in fruit from both temperatures (Tables 5) but acidity remained higher in fruit from the lower temperature (Table 6). There were no physiological disorders in fruit from either temperature examined immediately after removal (Tables 7 and 9) but a low incidence of breakdown and core flush was recorded in fruit from both temperatures after a further seven days at 20ºC (Tables 8 and 10). Slightly higher incidences of disorders were recorded in fruit stored at the lower temperature.

Removal 3

At the third examination of the stored fruit in late February (153 days) fruit stored at the lower temperature were firmer (Table 3). However, there was a larger benefit of the lower temperature on the firmness of fruit subjected to a further seven days at 20ºC. Those stored at 0-0.5ºC were 6.2N (0.6kg) firmer than those stored at the higher (recommended) temperature of 1.5-2ºC (Table 4). Fruits stored at the lower temperature were higher in soluble solids and acid concentration (Tables 5 and 6). A low incidence of breakdown and core flush was recorded in fruits examined immediately after storage (Tables 7 and 9) but these were restricted to one CA condition (see below). There was no effect of storage temperature. The incidence of both disorders increased during a seven-day period at 20ºC but remained restricted to one CA regime (see below). Breakdown tended to be worse in fruit stored at the higher temperature but there was little effect of temperature on the level of core flush (Tables 8 and 10).

Removal 4

At the fourth examination of the stored fruit in mid-April (178 days) the firmness of the fruit immediately ex-store was again higher in fruit stored at the lower temperature (Table 3). After a further seven days at 20ºC those stored at 0-0.5ºC were 3.5N (0.4kg) firmer than those stored at the higher (recommended) temperature (Table 4). Contrary to the results obtained at the previous removal the soluble solids concentration was higher in fruits stored at the higher temperature (Table 5). There was no effect of storage temperature on acid concentration in the fruit (Table 6). The incidence of breakdown had increased two-fold in the 25 days between removal 3 and removal 4 (Table 7) and again was restricted to one CA condition (see below). There was no apparent effect of storage temperature on the incidence of breakdown either immediately ex-store or after a further seven days at 20ºC (Table 8). A low incidence of core flush was recorded in fruit immediately ex-store but this increased markedly during a further seven days at 20ºC (Tables 9 and 10). There was no effect of storage temperature on the incidence of core flush.

Overall effects of CA conditions

Removal 1

At the first examination of the stored fruit in mid-November (55 days) there was no significant effect of CA conditions on the firmness of the fruit immediately ex-store (Table 3). However after a further seven days at 20°C the fruit stored in 8/13 had lost 17.5N (1.8kg) of firmness compared with 5.5-8.2N (0.6-0.8kg) in fruit from the other CA regimes (Table 4). There were no significant effects of CA treatments on soluble solids concentrations but acid concentrations were significantly affected with least acid in fruit from the 8/13 regime (Tables 5 and 6). There were no physiological disorders in the fruit immediately ex-store nor after a further seven days at 20°C (Tables 7-10).

Removal 2

It was clear at the second examination of the stored fruit in early January (106 days) that the ultra-low oxygen (ULO) regimes (<1/1 and 5/1) were maintaining firmness better than <1/2 and 8/13 (Table 3). The effect was particularly noticeable after a further seven days at 20°C (Table 4). There were no significant effects of CA treatments on soluble solids concentrations in the fruit but acidity was again affected significantly with lowest levels again associated with the 8/13 regime (Tables 5 and 6). There were no physiological disorders in the fruit immediately ex-store (Tables 7 and 9) but breakdown and core flush developed in fruit stored in 8/13 and subjected to a further seven days at 20°C (Tables 8 and 10). The pronounced softening and development of disorders in fruit stored in 8/13 endorses the recommended duration (early November) for storage under these conditions. This recommendation is made in spite of the fact that some orchards may not develop disorders when stored beyond November. In this study, breakdown and core flush affected fruit from four of the six orchards (Tables 8-10). However in order to provide an industry standard recommendation no allowance can be made for orchards that produce fruit that are less prone to disorders. This may be possible once the storage potential of individual consignments of fruit can be estimated.

Removal 3

At the third examination of the stored fruit in late February (153 days) the firmness benefit from ULO storage conditions (<1/1 and 5/1) over <1/2 and 8/13 were marked ex-store but particularly so after a further 7 days at 20°C (Tables 3 and 4). Again there were no effects of CA regimes on soluble solids concentrations (Table 5) but effects on acid concentrations were again significant. The low acid in fruit stored in 8/13 (Table 6) was a possible reaction to the development of breakdown that was restricted to fruit in these conditions (Table 7 and 8). Similarly the development of core flush was restricted primarily to the 8/13 CA condition (Tables 9 and 10).

Removal 4

At the fourth examination of the stored fruit in mid-April (178 days) there was a marked effect of CA treatments on the firmness of the fruit immediately ex-store (Table 3). There was a 16.7N (1.7kg) difference in firmness between fruit stored in 5/1 and that stored in <1/2. The order of CA effects on firmness endorses the sequence of marketing proposed in recommendations based on earlier research funded by APRC i.e. 8/13 early November, <1/2 early January, <1/1 mid February and 5/1 early April. Consistent with all previous removals the effects of CA conditions on soluble solids concentration were not significant (Table 5). Acid concentrations were low in fruit stored in <1/2 and 8/13 compared with the ULO regimes (Table 6). As in the previous removal breakdown and core flush was restricted mainly to fruit stored in 8/13.

Temperature / CA interactions (data not presented)

The effect of storage temperature on firmness varied according to the CA condition imposed particularly later in the storage period (153 and 178 days). There was no firmness benefit from reduced temperature in 8/13 storage later in the storage period when breakdown was evident in the fruit. The lack of firmness benefit is therefore somewhat academic in that 8/13 is unsuitable for storage beyond early November. Firmness benefits ex-store resulting from storage at the lower temperature were generally small where fruit was stored in 5/1 although there was a greater benefit after a further seven days at 20^{o}C. This result emphasizes the lack of softening that occurred in the 5/1 regime regardless of the storage temperature.

Overall effects of Orchards

At every removal there were highly significant effects of orchard on all quality attributes. This emphasizes the need for future studies to understand the factors that effect the response of individual consignments of Gala apples to applied storage conditions. This can only be achieved in large-scale survey experiments to evaluate pre-harvest factors such as nutrition and maturity. In the meantime storage advice will continue to be tailored to the least robust consignments.

Table 3. Gala storage trial 2000-01. The overall effects of storage temperature, controlled atmosphere conditions and orchard site on the **firmness (N)** of apples removed from store after 55, 106, 153 and 178 days. The standard error of the differences between means (s.e.d.) and the residual degrees of freedom (d.f.) are provided to test means for statistical significance.

Firmness		°C							
	Days in store	0-0.5	1.5-2				Significance of temperature effect	s.e.d.##	d.f.
Effects of temperature	55	78.0	76.5				*	-	
	106	73.3	72.7				n.s.	-	
	153	69.9	68.3				**	-	
	178	65.6	63.2				***	-	
		CO_2/O_2							
		<1/1	<1/2	5/1	8/13				
Effects of CA	55	77.7	76.4	76.7	78.0			0.79	8
	106	74.7	70.6	75.2	71.4			0.69	8
	153	70.8	62.5	75.4	67.6			0.60	8
	178	65.2	56.8	73.5	62.2			0.66	8
		Orchard reference							
		Kent W	Kent C	Kent P	Kent Pt	E Ang W	E Ang L		
Effects of orchard	55	80.1	78.1	75.9	75.3	76.6	77.4	0.47	40
	106	76.7	72.8	72.2	69.7	72.8	73.9	0.58	40
	153	72.6	67.8	68.1	65.0	70.1	71.1	0.65	40
	178	67.7	63.8	61.6	61.2	64.6	67.5	0.62	40

*,**,*** and n.s. indicates significant effect of temperature at the 5%, 1% and 0.1% level of probability and non-significant effect respectively. ## - experiment structure does provide an s.e.d. for temperature effects.

Table 4. Gala storage trial 2000-01. The overall effects of storage temperature, controlled atmosphere conditions and orchard site on the **firmness (N)** of apples removed from store after 55, 106, 153 and 178 days and subjected to a further seven days at 20°C. The standard error of the differences between means (s.e.d.) and the residual degrees of freedom (d.f.) are provided to test means for statistical significance.

Firmness		°C							
	Days in store	0-0.5	1.5-2				Significance of temperature effect[#]	s.e.d.[##]	d.f.
Effects of temperature	55	67.7	67.5				n.s.	-	
	106	68.6	66.4				**	-	
	153	66.9	60.7				***	-	
	178	61.3	57.8				***	-	
		CO_2/O_2							
		<1/1	<1/2	5/1	8/13				
Effects of CA	55	72.2	68.2	69.5	60.5			0.60	8
	106	72.2	62.3	75.5	60.0			0.66	8
	153	67.2	55.4	75.9	56.8			0.48	8
	178	61.4	50.1	75.0	51.8			0.69	8
		Orchard reference							
		Kent W	Kent C	Kent P	Kent Pt	E Ang W	E Ang L		
Effects of orchard	55	72.0	68.8	66.4	62.6	67.8	68.0	0.55	40
	106	72.3	66.6	66.8	62.3	67.6	69.4	0.40	40
	153	67.2	60.5	62.5	60.6	64.8	67.4	0.61	40
	178	62.8	57.9	56.2	55.8	61.3	63.5	0.64	40

*,**,*** and n.s. indicates significant effect of temperature at the 5%, 1% and 0.1% level of probability and non-significant effect respectively.

[##] - experiment structure does provide an s.e.d. for temperature effects.

Table 5. Gala storage trial 2000-01. The overall effects of storage temperature, controlled atmosphere conditions and orchard site on the concentration of **soluble solids (%SS)** in apples removed from store after 55, 106, 153 and 178 days. The standard error of the differences between means (s.e.d.) and the residual degrees of freedom (d.f.) are provided to test means for statistical significance.

%SS		°C							
	Days in store	0-0.5	1.5-2				Significance of temperature effect[#]	s.e.d.[##]	d.f.
Effects of temperature	55	11.8	12.1				*	-	
	106	12.4	12.3				n.s.	-	
	153	12.4	12.1				*	-	
	178	12.0	12.4				**	-	
		CO_2/O_2							
		<1/1	<1/2	5/1	8/13				
Effects of CA	55	12.1	11.8	12.0	11.9			0.10	8
	106	12.6	12.2	12.3	12.2			0.10	8
	153	12.3	12.1	12.4	12.2			0.12	8
	178	12.5	12.1	12.3	12.0			0.16	8
		Orchard reference							
		Kent W	Kent C	Kent P	Kent Pt	E Ang W	E Ang L		
Effects of orchard	55	11.4	12.6	12.4	11.8	12.3	11.3	0.16	40
	106	12.0	12.9	12.8	12.1	12.6	11.7	0.13	40
	153	11.8	12.9	12.8	11.8	12.4	11.7	0.12	40
	178	12.0	12.7	12.7	11.8	12.4	11.8	0.13	40

*,**,*** and n.s. indicates significant effect of temperature at the 5%, 1% and 0.1% level of probability and non-significant effect respectively.

[##] - experiment structure does provide an s.e.d. for temperature effects.

Table 6. Gala storage trial 2000-01. The overall effects of storage temperature, controlled atmosphere conditions and orchard site on the titratable **acidity** (g malic acid kg^{-1} of juice) of apples removed from store after 55, 106, 153 and 178 days. The standard error of the differences between means (s.e.d.) and the residual degrees of freedom (d.f.) are provided to test means for statistical significance.

Acidity		°C							
	Days in store	0-0.5	1.5-2					Significance of temperature effect[#]	s.e.d.[##]	d.f.
Effects of temper ature	55	3.7	3.6					**	-	
	106	3.5	3.3					**	-	
	153	3.2	3.1					*	-	
	178	2.9	2.9					n.s.	-	
		CO_2/O_2								
		<1/1	<1/2	5/1	8/13					
Effects of CA	55	3.8	3.7	3.7	3.6				0.03	8
	106	3.5	3.4	3.4	3.3				0.04	8
	153	3.3	3.1	3.2	2.9				0.04	8
	178	3.1	2.8	3.1	2.6				0.03	8
		Orchard reference								
		Kent W	Kent C	Kent P	Kent Pt	E Ang W	E Ang L			
Effects of orchard	55	3.8	3.7	4.3	3.4	3.5	3.5		0.05	40
	106	3.5	3.3	3.8	3.3	3.2	3.2		0.05	40
	153	3.3	3.0	3.6	3.0	2.9	3.0		0.04	40
	178	3.0	2.8	3.3	2.9	2.6	2.8		0.04	40

*,**,*** and n.s. indicates significant effect of temperature at the 5%, 1% and 0.1% level of probability and non-significant effect respectively.

[##] - experiment structure does provide an s.e.d. for temperature effects.

Table 7. Gala storage trial 2000-01. The overall effects of storage temperature, controlled atmosphere conditions and orchard site on the incidence (%) of **internal breakdown** in apples removed from store after 55, 106, 153 and 178 days. Analysis of variance was not appropriate for these data due to their skewed distribution and the high proportion of samples without breakdown. Consequently, standard errors of the differences between means (s.e.d.) and the residual degrees of freedom (d.f.) are not provided.

Breakdown	Days in store	°C 0-0.5	°C 1.5-2				
Effects of temperature	55	0	0				
	106	0	0				
	153	3.5	3.3				
	178	6.5	8.5				
		CO_2/O_2 <1/1	CO_2/O_2 <1/2	CO_2/O_2 5/1	CO_2/O_2 8/13		
Effects of CA	55	0	0	0	0		
	106	0	0	0	0		
	153	0	0	0	13.8		
	178	0	0	0	30.0		
		Orchard reference Kent W	Kent C	Kent P	Kent Pt	E Ang W	E Ang L
Effects of orchard	55	0	0	0	0	0	0
	106	0	0	0	0	0	0
	153	3.1	4.4	8.1	4.4	0.6	0
	178	8.1	10.6	13.8	4.4	8.1	0

Table 8. Gala storage trial 2000-01. The overall effects of storage temperature, controlled atmosphere conditions and orchard site on the incidence (%) of **internal breakdown** in apples removed from store after 55, 106, 153 and 178 days and subjected to a further seven days at 20°C. Analysis of variance was not appropriate for these data due to their skewed distribution and the high proportion of samples without breakdown. Consequently, standard errors of the differences between means (s.e.d.) and the residual degrees of freedom (d.f.) are not provided.

Breakdown		°C	
	Days in store	0-0.5	1.5-2
Effects of temperature	55	0	0
	106	2.1	0.4
	153	10.8	14.6
	178	16.9	19.6

		CO_2/O_2			
		<1/1	<1/2	5/1	8/13
Effects of CA	55	0	0	0	0
	106	0	0	0	5.0
	153	0	0.4	0.4	50.0
	178	0	0	3.3	69.6

		Orchard reference					
		Kent W	Kent C	Kent P	Kent Pt	E Ang W	E Ang L
Effects of orchard	55	0	0	0	0	0	0
	106	0	0.6	5.0	1.3	0.6	0
	153	9.4	18.8	21.9	6.9	17.5	1.9
	178	20.6	21.9	15.6	15.6	15.6	20.0

Table 9. Gala storage trial 2000-01. The overall effects of storage temperature, controlled atmosphere conditions and orchard site on the incidence (%) of **core flush** in apples removed from store after 55, 106, 153 and 178 days. Analysis of variance was not appropriate for these data due to their skewed distribution and the high proportion of samples without breakdown. Consequently, standard errors of the differences between means (s.e.d.) and the residual degrees of freedom (d.f.) are not provided.

Core Flush		°C					
	Days in store	0-0.5	1.5-2				
Effects of temperature	55	0	0				
	106	0	0				
	153	0.21	0.21				
	178	2.29	1.46				
		CO_2/O_2					
		<1/1	<1/2	5/1	8/13		
Effects of CA	55	0	0	0	0		
	106	0	0	0	0		
	153	0	0	0	0.83		
	178	0	0	1.25	6.25		
		Orchard reference					
		Kent W	Kent C	Kent P	Kent Pt	E Ang W	E Ang L
Effects of orchard	55	0	0	0	0	0	0
	106	0	0	0	0	0	0
	153	0	0.63	0	0	0.63	0
	178	0.63	1.25	6.88	1.25	1.25	0

Table 10. Gala storage trial 2000-01. The overall effects of storage temperature, controlled atmosphere conditions and orchard site on the incidence (%) of **core flush** in apples removed from store after 55, 106, 153 and 178 days followed by a further seven days at 20ºC. Analysis of variance was not appropriate for these data due to their skewed distribution and the high proportion of samples without breakdown. Consequently, standard errors of the differences between means (s.e.d.) and the residual degrees of freedom (d.f.) are not provided.

Core Flush		ºC	
	Days in store	0-0.5	1.5-2
Effects of temperature	55	0	0
	106	4.17	1.88
	153	8.54	6.87
	178	18.5	15.8

		CO_2/O_2			
		<1/1	<1/2	5/1	8/13
Effects of CA	55	0	0	0	0
	106	0	0	0	12.08
	153	0.42	0.42	0.83	29.17
	178	2.1	3.8	7.1	55.8

		Orchard reference					
		Kent W	Kent C	Kent P	Kent Pt	E Ang W	E Ang L
Effects of orchard	55	0	0	0	0	0	0
	106	0	4.37	6.87	3.12	3.75	0
	153	5.00	6.88	20.0	5.00	9.38	0
	178	15.6	27.5	16.3	19.4	11.9	12.5

Year 2 (2001/2002)

There were no effects of storage temperature on background colour, greasiness or the incidence of rotting (data not presented). These characteristics were influenced markedly by harvest date (see below). There was insufficient development of scald to determine any possible affect of storage temperature.

Storage in 8% CO_2 + 13% O_2 (8/13)

Fruit stored in the 8/13 regime were free of internal physiological disorders when stored until early November and subjected to a further seven days at 20ºC (simulated marketing period or SMP) (Tables 12 and 13). Fruit stored until mid-January (+ SMP) developed core flush and breakdown. HRI's recommendation to limit the storage of Gala in the 8/13 regime to early November was endorsed by these results although more frequent removals of fruit between early November and mid-January would have defined more precisely the maximum duration of storage.

There was a firmness benefit of storing fruit at the lower temperature (Table 14). Early harvesting (Pick 1) gave firmer fruit than later harvesting (Picks 2 and 3) and there was an additive effect of early harvesting and lower storage temperature on firmness.

The lack of any adverse response to the lower temperature for Gala stored in 8/13 until November should encourage growers to maintain storage (fruit) temperatures of 0-0.5 ºC that is already recommended for air storage. Where storage in 8/13 was extended to mid-January and beyond, the lower storage temperature resulted in less flesh breakdown but enhanced core flush. Clearly it is important to avoid over-storing fruit in the 8/13 regime in order to avoid customer dissatisfaction. It is likely that adverse effects will be noted after purchase in fruit that is deemed to be sound at the point of grading. Low oxygen regimes are required for Gala stored after early November (see below).

Storage in <1% CO_2 + 2% O_2 (<1/2)

Fruit stored in the <1/2 regime were free of internal physiological disorders when stored until mid January and subjected to a further seven days at 20ºC (simulated marketing period or SMP) (Tables 12 and 13). Fruit stored until mid-February (+ SMP) were virtually free core flush and breakdown but were affected by both disorders when stored until early April (Tables 12 and 13). HRI's recommendation to limit the storage of Gala in the <1/2 regime to early January was endorsed by these results.

There was a clear overall firmness benefit from storing at the lower temperature but contrary to the results for 8/13 storage there was no consistent effect of harvest date (Table 14). In the absence of any adverse response to the lower storage temperature it seems appropriate to recommend a storage (fruit) temperature of 0-0.5 ºC for <1/2 storage until early January.

Storage in <1% CO_2 + 1% O_2 (<1/1)

Fruit stored in the <1/1 regime were virtually free of internal physiological disorders when stored until mid February and subjected to a further seven days at 20°C (simulated marketing period or SMP) (Tables 12 and 13). The fruit was markedly firmer than those from <1/2 storage removed a month earlier (Table 14). Where storage was extended to early April fruits were affected by internal breakdown and to a lesser extent core flush (Tables 12 and 13). In April the lower storage temperature tended to increase the incidence of core flush and breakdown although fruit harvested on the first occasion were virtually free of disorders. Current advice is not to extend storage in the <1/1 regime beyond mid February. These data support this advice and show increased susceptibility to internal disorders with extended storage particularly at lower storage temperatures and in fruit of more advanced maturity at harvest.

There was a firmness benefit of storing fruit at the lower temperature (Table 14). Late harvesting (Pick 3) gave softer fruit than earlier harvesting (Picks 1 and 2) and there was an additive effect of early harvesting and lower storage temperature on firmness. In the absence of any adverse response to the lower storage temperature it seems appropriate to recommend a storage (fruit) temperature of 0-0.5°C for <1/1 storage until mid February.

Storage in 5% CO_2 + 1% O_2 (5/1)

Only early picked fruit (Pick 1) stored at the higher temperature 1.5-2°C were free of internal physiological disorders when stored in 5/1 until early April followed by a further seven days at 20°C (Tables12 and 13). Although storage at 0-0.5°C improved firmness (Table 16) the increased incidences of core flush and breakdown would preclude the use of the lower temperature for commercial purposes.

Effects of harvest date

There appears to be no clear guidance on criteria for acceptable visual appearance in Gala. Clearly there is market resistance to greasy apples. Consequently attempts were made to estimate greasiness by squeezing the apples in an attempt to generate a sound (see Annexe to the report). Where it was not possible to generate a sound then apples were considered to be greasy. In many cases the apples were not obviously greasy but were considered to be dull and lacking freshness.

Whilst a minimum amount of red colour is required (50%) there has been some market resistance to Gala clones such as Galaxy and Brookfield that develop a very dark blush. However, recent indications are that intensity of colour is less important than achieving uniformity of colour within the packaged product. The number of fruits considered to have a very dark red colour was recorded so that the impact of harvest date could be assessed. Similarly the background colour of the non-blush side of the fruit was assessed using commercial (WorldWide Fruit / Qualytech) colour charts. Background colour of each fruit was compared against 4 cards that range from green (1) to yellow (4). The average score was calculated for each sample.

Table 11. Effect of **harvest date** in 2001 on harvest maturity of Gala apples

	Harvest date		
	24.9.01	1.10.01	8.10.01
Orchard P			
Internal ethylene conc. (ppb)	66	214	-
Internal ethylene conc. (log_{10} ppb)	1.4	2.2	-
Internal ethylene conc. (% > 100 ppb)	20	50	-
Starch pattern Ctifl chart (1, black -10, white)	3.0	4.7	6.0
Firmness (N)	91.4	85.0	77.9
Soluble solids (%)	11.2	11.0	11.3
Orchard W			
Internal ethylene conc. (ppb)	157	747	-
Internal ethylene conc. (log_{10} ppb)	1.9	2.8	-
Internal ethylene conc. (% > 100 ppb)	30	100	-
Starch pattern Ctifl chart (1, black -10, white)	5.7	8.3	8.6
Firmness (N)	89.0	85.7	79.5
Soluble solids (%)	10.5	11.4	11.5

- Data not recorded

It is clear that by following HRI's recommendations for the storage of Gala, as detailed in the Best Practice Guide for UK Apple Production, the firmness and internal quality of the fruit should be acceptable for retailers and consumers. In the 2001 crop acceptable firmness and internal quality was generally achieved for fruit picked from 24 September to 8 October **although it was important not to extend storage beyond the period recommended for any particular CA regime**. **For 5/1 storage until early April only early picking (24 September) provided fruit without internal defects.** As expected background colour was more yellow in later picked fruit (Table 15). If a score of 3 (yellow/green) was considered to be the commercial maximum then clearly pick 3 (8 October) was too late. If a high percentage of fruit with dark red blush were considered a marketing disadvantage then earlier picking would be necessary. Greasiness was apparent in low oxygen, low carbon dioxide storage conditions and was worsened by delayed harvesting.

In April none of the fruit stored in 5/1 and only 8.6% of those from 8/13 storage (data not presented) were considered greasy whereas 31.7% and 12.5% of fruit from <1/2 and <1/1 respectively failed the test for greasiness (data not presented). More work may be required on factors affecting greasiness using methods that quantify wax production. The amount of fungal rotting increased with harvest delay.

Fruit harvested over a two-week period (24 September - 8 October) in 2001 did not develop storage disorders when stored in CA conditions of 8/13, <1/2 and <1/1 for the recommended periods. On 8 October average levels of starch (1-10 on Ctifl chart), firmness (N) and soluble solids (%) were 7.3, 78.7 and 11.4 respectively. Fruit stored in 5/1 until early April must be picked before ripening on the tree is too advanced. In 2001 only the first pick of fruit was suitable for long-term storage in 5/1.

Average picking date criteria for successful 5/1 storage in 2001 were 4.4 on the Ctifl starch chart, 90.2 N (9.2 kg) firmness, 10.9 (%) soluble solids and 25% of fruits with internal ethylene concentrations above the ripening threshold of 100 ppb.

Table 12. Gala storage trial 2001-02. The overall effects of storage temperature, controlled atmosphere conditions, harvest date and storage duration on the incidence (%) of **core flush**. Fruits were held for a further seven days at 20°C prior to examination. Dates for picks 1, 2 and 3 were 24 September and 1 and 8 October 2001 respectively.

CO_2 / O_2	Temp. °C	Pick	Date fruit removed from CA storage			
			5.11.01	15/16.1.02	13-15.2.02	10-16.4.02
8/13	1-1.5	1	0	45.0	70.0	-
		2	0	35.0	60.0	-
		3	0	52.5	70.0	-
	0-0.5	1	0	12.5	37.5	-
		2	0	10.0	32.5	-
		3	0	7.5	20.0	-
<1/2	1-1.5	1	-	0	0	2.5
		2	-	0	0	10.0
		3	-	0	0	2.5
	0-0.5	1	-	0	0	10.0
		2	-	0	0	15.0
		3	-	0	0	22.5
<1/1	1-1.5	1	-	-	0	0
		2	-	-	0	0
		3	-	-	0	2.5
	0-0.5	1	-	-	0	0
		2	-	-	0	2.5
		3	-	-	0	10.0
5/1	1-1.5	1	-	-	-	0
		2	-	-	-	5.0
		3	-	-	-	7.5
	0-0.5	1	-	-	-	12.5
		2	-	-	-	25.0
		3	-	-	-	12.5

(- Data not recorded)

Table 13. Gala storage trial 2001-02. The overall effects of storage temperature, controlled atmosphere conditions, harvest date and storage duration on the incidence (%) of **internal breakdown**. Fruits were held for a further seven days at 20ºC prior to examination. Dates for picks 1, 2 and 3 were 24 September and 1 and 8 October 2001 respectively.

CO_2 / O_2	Temp. ºC	Pick	Date fruit removed from CA storage			
			5.11.01	15/16.1.02	13-15.2.02	10-16.4.02
8/13	1-1.5	1	0	17.5	32.5	-
		2	0	22.5	30.0	-
		3	0	27.5	47.5	-
	0-0.5	1	0	35.0	62.5	-
		2	0	37.5	42.5	-
		3	0	47.5	60.0	-
<1/2	1-1.5	1	-	0	0	7.5
		2	-	0	2.5	25.0
		3	-	0	0	47.5
	0-0.5	1	-	0	0	2.5
		2	-	0	0	10.0
		3	-	0	0	37.5
<1/1	1-1.5	1	-	-	0	0
		2	-	-	0	10.0
		3	-	-	2.5	40.0
	0-0.5	1	-	-	0	2.5
		2	-	-	0	27.5
		3	-	-	0	30.0
5/1	1-1.5	1	-	-	-	0
		2	-	-	-	2.5
		3	-	-	-	35
	0-0.5	1	-	-	-	10.0
		2	-	-	-	42.5
		3	-	-	-	60.0

(- Data not recorded)

Table 14. Gala storage trial 2001-02. The effects of storage temperature and harvest date on the **firmness (N)** of Gala apples held in CA conditions for the periods recommended by HRI. Fruits were held for a further seven days at 20°C prior to examination. Dates for picks 1, 2 and 3 were 24 September and 1 and 8 October 2001 respectively. Strictly the s.e.d.'s provided should be used for comparing means for the same level of temperature.

Removal date	CO_2 / O_2	Temp. °C	Pick 1	Pick 2	Pick 3
5.11.01	8/13	1.5-2	63.4	60.5	59.8
		0-0.5	65.4	62.9	62.9
				s.e.d. = 1.32 (10 d.f.)	
15.1.02	<1/2	1.5-2	61.7	64.3	59.5
		0-0.5	64.3	66.9	64.8
				s.e.d. = 1.18 (22 d.f.)	
13.2.02	<1/1	1.5-2	73.8	70.6	64.5
		0-0.5	74.5	73.9	68.1
				s.e.d. = 1.58 (34 d.f.)	
10.4.02	5/1	1.5-2	78.5	76.3	65.2
		0-0.5	82.9	78.2	73.0
				s.e.d. = 2.05 (34 d.f.)	

Table 15. Gala storage trial 2001-02. The overall effects harvest date on the **external quality** of Gala apples held in CA conditions for the periods recommended by HRI. Dates for picks 1, 2 and 3 were 24 September and 1 and 8 October 2001 respectively.

Removal date	CO_2 / O_2		Pick 1	Pick 2	Pick 3
5.11.01	8/13	% Scald	0	0	0
		Ground colour (1-4)	-	-	-
		% Dark red	-	-	-
		% Greasy	-	-	-
15.1.02	<1/2	% Scald	0	0	0
		Ground colour	2.9	2.7	3.5
		% Dark red	8.8	23.8	60.0
		% Greasy	-	-	-
13.2.02	<1/1	% Scald	0	0	0
		Ground colour	2.4	3.0	3.1
		% Dark red	3.8	13.8	37.5
		% Greasy	26.2	75.0	83.7
10.4.02	5/1	% Scald	0	0	0
		Ground colour	2.5	2.6	3.2
		% Dark red	1.3	21.3	43.8
		% Greasy	0	0	0
10.4.02	All	% Rots	4.9	7.3	12.1

(- Data not recorded)

Year 3 (2002/2003)

There were no generally no effects of storage temperature on background colour, greasiness or the incidence of rotting (data not presented). Background colour and greasiness were influenced markedly by harvest date (see below). Since scald did not develop during storage it was not possible to determine any possible affect of storage temperature.

Harvest maturity

As mentioned earlier in the report the more practical measures of harvest maturity are firmness, soluble solids (sugar) content and the extent of starch conversion. No precise guidelines have been developed to indicate optimum harvest maturity in relation to storage. Previous work suggested that Gala stored well when picked at above 7kg (70 N) firmness and over a broad range of starch levels (50-90% black). In comparison with these criteria the apples from the orchards in the study were very firm at all pick dates and starch levels were 50% or higher at the final pick. Although starch and firmness declined markedly over the 14-day harvesting period there was generally little change in the concentration of soluble solids (Table 16). Increase in ethylene production is the true physiological marker of ripening. Internal ethylene concentration (IEC) in excess of 100 ppb normally indicates that an apple has commenced ripening and apples for long-term storage are usually picked just prior to this event. The IEC data in Table 16 suggests that a high proportion (90%) of fruit in both orchards were ripening when harvested on 24 September and that the first pick (17 September) may have been most appropriate for storage.

Table 16. Effect of **harvest date** in 2002 on harvest maturity of Gala apples

	Harvest date		
	17.9.02	24.9.02	1.10.02
Orchard P			
Internal ethylene conc. (ppb)	176	388	1430
Internal ethylene conc. (% > 100 ppb)	40	90	100
Starch pattern Ctifl chart (1, black -10, white)	2.8	4.0	7.8
Starch % black (approx.)	89	82	50
Firmness (N)	92.1	92.1	85.1
Firmness (kg)	9.4	9.4	8.7
Soluble solids (%)	10.2	10.4	11.4
Orchard W			
Internal ethylene conc. (ppb)	500	1173	1912
Internal ethylene conc. (% > 100 ppb)	70	90	100
Starch pattern Ctifl chart (1, black -10, white)	2.6	5.9	7.1
Starch % black (approx.)	90	69	59
Firmness (N)	94.1	85.6	86.8
Firmness (kg)	9.6	8.7	8.8
Soluble solids (%)	9.7	10.3	10.7

Recent work by the Quality Fruit Group (QFG) suggests that early picked Gala (starch above 80%) have the best eating quality after long-term storage (QFG Newsletter No. 3 - 5 September 2002). On that basis commercial harvesting in orchard P and W should have been completed by 24 September and between 17 and 24 September in orchards P and W respectively. In orchards P and W the rate of loss of firmness and starch increased markedly from 24 September - 1 October and from 17-24 September respectively.

It is difficult to compare the maturation of fruit in these orchards in 2001 and 2002 since the various maturity parameters provide different indications. On the basis of increase in ethylene concentration in the fruit 2002 could be judged as one-two weeks earlier than 2001. However starch and firmness results indicate that 2002 was up to a week early and soluble solids data suggest that 2002 was actually later than 2001. Ultimately it is the relationship between harvest date and storage quality that is important and will define harvest maturity parameters for Gala. By the final harvest (1 October) water core was present in 30% and 40% of fruit from orchards P and W respectively. Water core development was consistent with the fruit reaching an advanced stage of maturity on the basis of internal ethylene and starch measurements.

Storage in 8% CO_2 + 13% O_2 (8/13)

As in the previous year fruit stored in the 8/13 regime were free of internal physiological disorders when stored until early November and subjected to a further seven days at 20ºC (simulated marketing period or SMP) (Tables 17 and 18). Fruit stored until mid-January (+ SMP) again developed core flush and breakdown. HRI's recommendation to limit the storage of Gala in the 8/13 regime to early November was endorsed by these results although more frequent removals of fruit between early November and mid-January would have defined more precisely the maximum duration of storage.

There was a firmness benefit of storing fruit at the lower temperature (Table 19). Early harvesting (Pick 1) gave firmer fruit than later harvesting (Picks 2 and 3) and there was an additive effect of early harvesting and lower storage temperature on firmness. Thus fruit from the first pick stored at the lower temperature was the firmest (69.9 N) and that from the final pick stored at the higher temperature was the least firm (62.8 N) (fruit subjected to a SMP).

The lack of any adverse response to the lower temperature for Gala stored in 8/13 until November should encourage growers to maintain storage (fruit) temperatures of 0-0.5 ºC that is already recommended for air storage. Where storage in 8/13 was extended to mid-January and beyond the lower storage temperature resulted in less core flush but similar or increased levels of flesh breakdown. This was similar to the results obtained in the previous year although there was an error in the APRC Report to June 30 2002 indicating that the lower storage temperature increased core flush and reduced breakdown. Clearly it is important to avoid over-storing fruit in the 8/13 regime in order to avoid customer dissatisfaction. It is likely that adverse effects will be noted after purchase in fruit that is deemed to be sound at the point of grading. Low oxygen regimes are required for Gala stored after early November (see below).

Storage in <1% CO_2 + 2% O_2 (<1/2)

Fruit stored in the <1/2 regime were free of internal physiological disorders when stored until mid January and subjected to a further 7 days at 20°C (simulated marketing period or SMP) (Tables 17 and 18). Fruit stored until mid-February (+ SMP) were virtually free core flush but breakdown affected fruit from the second and third picks (Tables 17 and 18). HRI's recommendation to limit the storage of Gala in the <1/2 regime to early January was endorsed by these results.

There was a firmness benefit of storing fruit at the lower temperature (Table 19). Early harvesting gave firmer fruit than later harvesting and there was an additive effect of early harvesting and lower storage temperature on firmness. Thus fruit from the first pick stored at the lower temperature was the firmest (74.0 N) and that from the final pick stored at the higher temperature was the least firm (63.9 N) (fruit subjected to a SMP).

In the absence of any adverse response to the lower storage temperature during the period advised for this CA condition it seems appropriate to recommend a storage (fruit) temperature of 0-0.5 °C for <1/2 storage until early January. Where storage in <1/2 was extended to mid-February and beyond the lower storage temperature resulted in more core flush and flesh breakdown.

Storage in <1% CO_2 + 1% O_2 (<1/1)

Fruit stored in the <1/1 regime were free of core flush when stored until mid February and subjected to a further seven days at 20°C (simulated marketing period or SMP). Breakdown occurred to a slight extent but not in fruit harvested on the first occasion (Tables 17 and 18). The fruit was as firm or firmer than those from <1/2 storage removed a month earlier (Table 19). Where storage was extended to early April fruits were affected by internal breakdown which was exacerbated by storage at the lower storage temperature (Table 18). Current advice is not to extend storage in the <1/1 regime beyond mid February. These data support this advice and show increased susceptibility to internal breakdown with extended storage particularly at lower storage temperatures and in fruit of more advanced maturity at harvest.

There was a firmness benefit of storing fruit at the lower temperature (Table 19). Delays in harvesting resulted in progressively softer fruit. There was an additive effect of early harvesting and lower storage temperature on the retention of firmness. In the absence of any adverse response to the lower storage temperature it seems appropriate to recommend a storage (fruit) temperature of 0-0.5°C for <1/1 storage until mid February.

Storage in 5% CO_2 + 1% O_2 (5/1)

In the previous year only early picked fruit (Pick 1) stored at the higher temperature 1.5-2°C were free of internal physiological disorders when stored in 5/1 until early April followed by a further seven days at 20°C (see APRC Report to June 30 2002). In the 2002 trial only early picked fruit (Pick 1) stored at the higher temperature 1.5-2°C were free of internal breakdown when stored in 5/1 until early April followed by a further 7 days at 20°C but a low incidence of core flush (2.5%) was recorded (Table 17). The increased incidences of core flush and breakdown would preclude the use of

the lower temperature for commercial purposes. These data together with those obtained in the previous year emphasise the necessity to harvest at the correct stage of maturity in order to avoid the development of physiological disorders during a SMP. Harvesting on the first occasion in both years (24 September 2001 and 17 September 2002) would have provided fruit virtually free of disorders following 5/1 storage (+SMP) until early April.

Effects of harvest date

It is clear that by following HRI's recommendations for the storage of Gala, as detailed in the Best Practice Guide for UK Apple Production, that the firmness and internal quality of the fruit should be acceptable for retailers and consumers. In the 2002 crop acceptable firmness and internal quality was generally achieved for fruit picked from 17 September to 1 October **although it was important not to extend storage beyond the period recommended for any particular CA regime**. **For 5/1 storage until early April only early picking (17 September) provided fruit with minimal internal defects.**

As expected background colour was more yellow in later picked fruit (Table 20). If a score of 3 (yellow/green) was considered to be the commercial maximum then only fruit from pick 1 (17 September) would have satisfied this requirement whereas in 2001 fruit picked on 1 October were at or below a score of 3.

There is a strong market resistance to greasy apples. Greasiness was generally not apparent on fruit examined immediately after removal from store but seriously affected fruit subjected to a SMP (Table 20). Fruit stored in <1/1 and 5/1 were only slightly greasy but those stored in 8/13 and <1/2 were seriously affected and particularly fruit picked after 17 September.

Contrary to the results obtained in the 2002 crop the amount of fungal rotting did not increase with harvest delay. Scald did not develop on any of the stored fruit.

Table 17. Gala storage trial 2002-03. The overall effects of storage temperature, controlled atmosphere conditions, harvest date and storage duration on the incidence (%) of **core flush**. Fruits were held for a further seven days at 20°C prior to examination. Dates for picks 1, 2 and 3 were 17 and 24 September and 1 October 2002 respectively.

CO_2 / O_2	Temp. °C	Pick	Date fruit removed from CA storage			
			6.11.02	15-16.1.03	12-14.2.03	7-10.4.03
8/13	1.5-2	1	0	65.0	85.0	-
		2	0	80.0	95.0	-
		3	0	82.5	95.0	-
	0-0.5	1	0	15.0	40.0	-
		2	0	37.5	60.0	-
		3	0	61.4	80.0	-
<1/2	1.5-2	1	-	0	0	0
		2	-	0	0	0
		3	-	0	0	0
	0-0.5	1	-	0	0	5.0
		2	-	0	2.5	22.5
		3	-	0	0	36.1
<1/1	1.5-2	1	-	-	0	0
		2	-	-	0	0
		3	-	-	0	0
	0-0.5	1	-	-	0	0
		2	-	-	0	0
		3	-	-	0	7.5
5/1	1.5-2	1	-	-	-	2.5
		2	-	-	-	15.0
		3	-	-	-	15.0
	0-0.5	1	-	-	-	15.0
		2	-	-	-	62.5
		3	-	-	-	62.5

(- Data not recorded)

Table 18. Gala storage trial 2002-03. The overall effects of storage temperature, controlled atmosphere conditions, harvest date and storage duration on the incidence (%) of **internal breakdown**. Fruits were held for a further seven days at 20ºC prior to examination. Dates for picks 1, 2 and 3 were 17 and 24 September and 1 October 2002 respectively.

CO_2 / O_2	Temp. ºC	Pick	Date fruit removed from CA storage			
			6.11.02	15-16.1.03	12-14.2.03	7-10.4.03
8/13	1.5-2	1	0	25.0	57.5	-
		2	0	50.0	82.5	-
		3	0	60.0	77.5	-
	0-0.5	1	0	25.0	65.0	-
		2	0	52.5	85.0	-
		3	0	58.3	82.5	-
<1/2	1.5-2	1	-	0	0	5.0
		2	-	0	2.5	12.5
		3	-	0	7.5	32.5
	0-0.5	1	-	0	0	7.5
		2	-	0	5.0	17.5
		3	-	0	15.0	41.1
<1/1	1.5-2	1	-	-	0	0
		2	-	-	2.5	10.0
		3	-	-	0	15.0
	0-0.5	1	-	-	0	7.5
		2	-	-	2.5	17.5
		3	-	-	10.0	28.3
5/1	1.5-2	1	-	-	-	0
		2	-	-	-	25.0
		3	-	-	-	40.0
	0-0.5	1	-	-	-	12.5
		2	-	-	-	42.5
		3	-	-	-	57.5

(- Data not recorded)

Table 19. Gala storage trial 2002-03. The effects of storage temperature and harvest date on the **firmness (N)** of Gala apples held in CA conditions for the periods recommended by HRI. Fruits were held for a further seven days at 20°C prior to examination. Dates for picks 1, 2 and 3 were 17 and 24 September and 1 October 2002 respectively. Strictly the s.e.d.'s provided should be used for comparing means for the same level of temperature.

Removal date	CO_2 / O_2	Temp. °C	Pick 1	Pick 2	Pick 3
6.11.02	8/13	1.5-2	65.7	64.1	62.8
		0-0.5	69.9	66.7	64.5
				s.e.d. = 1.51 (10 d.f.)	
16.1.03	<1/2	1.5-2	66.7	64.7	63.9
		0-0.5	74.0	70.3	67.1
				s.e.d. = 1.34 (18 d.f.)	
14.2.03	<1/1	1.5-2	71.2	64.9	62.4
		0-0.5	78.1	74.7	69.0
				s.e.d. = 2.61 (9 d.f.)	
7.4.03	5/1	1.5-2	81.4	71.4	70.5
		0-0.5	82.8	74.3	71.4
				s.e.d. = 2.51 (12 d.f.)	

Table 20. Gala storage trial 2002-03. The overall effects harvest date on the **external quality** of Gala apples held in CA conditions for the periods recommended by HRI. Dates for picks 1, 2 and 3 were 17 and 24 September and 1 October 2002 respectively.

Removal date	CO_2 / O_2		Pick 1	Pick 2	Pick 3
6.11.02	8/13	% Scald	0	0	0
		Ground colour (1-4)	2.7	2.9	3.4
		% Greasy	0	2.5	5.0
		% Greasy (+7d at 20°C)	18.8	75.0	100
16.1.03	<1/2	% Scald	0	0	0
		Ground colour	2.9	3.1	3.5
		% Greasy	0	1.3	8.8
		% Greasy (+7d at 20°C)	23.8	90.0	97.5
14.2.03	<1/1	% Scald	0	0	0
		Ground colour	2.6	3.1	3.5
		% Greasy	0.4	0	1.3
		% Greasy (+7d at 20°C)	0.5	7.5	12.5
7.4.03	5/1	% Scald	0	0	0
		Ground colour	2.7	3.2	3.5
		% Greasy	0	0	0
		% Greasy (+7d at 20°C)	0	6.3	3.8
7-10.4.02	All	% Rots	4.3	5.8	4.9

(- Data not recorded)

Conclusions

On the basis of the results obtained over the three years of the project it appears that the storage temperature for Gala can be reduced from 1.5-2.0ºC to 0-0.5ºC for Gala in all recommended CA conditions except 5/1. The proposed changes to the recommendations provided in the Best Practice Guide for UK Apple Production are incorporated in Table 21.

There were consistent improvements in fruit firmness by storing Gala apples at 0-0.5ºC as opposed to 1.5-2ºC particularly where fruits were subjected to a further seven days at 20ºC (simulated marketing period). In the first year of the project (2000-01) where fruit were picked on one occasion only the effects of temperature were small compared with the effects of the different CA regimes. It is therefore more important to maintain the correct CA regime for the storage duration required than to reduce the storage temperature. The effect of storage temperature on soluble solids concentrations was inconsistent but acidity was retained more effectively at the lower temperature. The development of breakdown and core flush was associated primarily with CA regime and particularly with the 8/13 regime. Marketing fruit stored in these conditions in November would be sufficiently early to avoid concerns about disorder development. In 5/1 the increased incidences of core flush and breakdown that resulted from storage at the lower temperature (0-0.5ºC) dictates that no change is made to the recommended temperature (1.5-2ºC) specifically for this CA regime.

Although the lower temperature of storage often increased the incidence of breakdown in fruit stored in other regimes this effect occurred where fruit was stored for longer than the period recommended for any particular CA condition (Table 21).

Fruit harvested over a two-week period in 2001 (24 September - 8 October) and 2002 (17 September - 1 October) in 2001 were virtually free of storage disorders when stored in CA conditions of 8/13, <1/2 and <1/1 for the recommended periods and subjected to a simulated marketing period. This indicates that fruit picked at an advanced stage of maturity as indicated by the starch-iodine test (Ctifl score of 6-8.6 in 2001 and 7.3-7.5 in 2002) are acceptable for storage in CA (except 5/1) for the prescribed periods, which accords with the results of early work. Whilst it is important that fruits remain in a firm condition and free of physiological disorders it is also important that the skins of the fruit should not become greasy. To avoid the development of greasiness after storage it was necessary to harvest at a much earlier stage of maturity i.e. when starch had declined to a Ctifl score of about 3-5.7 in 2001 and 2.6-2.8 in 2002. The average Ctifl score for minimising greasiness in fruit from the same Kent orchards in 2001 and 2002 was 3.5 which is equivalent to a starch coverage of about 85%. This figure is close to that (starch above 80%) suggested by the Quality Fruit Group (QFG) to achieve the best eating quality after long-term storage (QFG Newsletter No. 3 - 5 September 2002).

Fruit for storage in 5/1 until early April must be picked before ripening on the tree is too advanced. In 2001 and 2002 only the first pick of fruit was suitable for long-term storage in 5/1. Based on the data obtained in the two Kent orchards in both years the picking date criteria for successful 5/1 storage were 3-4.4 on the Ctifl starch chart (78-88% black), 90-93 N (9.2-9.5 kg) firmness, 10-10.9 (%) soluble solids and 25-55% of fruits with internal ethylene concentrations above the ripening threshold of 100 ppb.

Table 21. Storage recommendations for Gala (all clones)

Controlled atmosphere (CA)							
No scrubber				Using a scrubber			
Temperature		% CO_2	Terminate	% CO_2	% O_2	Terminate	Notes
^oC	^oF						
0-0.5	32-33	8	Early Nov	<1	2	Early Jan	[1]
0-0.5	32-33			<1	1	Mid Feb	[2]
1.5-2.0	35-36			5	1	Early April	[2, 3, 4]

Air storage of Gala at 0-0.5^{o}C (32-33^{o}F) should be terminated by the middle of December

Notes:

5. Ensure that O_2 level does not fall below 1.7% when controlling manually at 2% O_2, aim to keep a mean of 2%
6. For operation at 1% O_2 use automatic equipment to control O_2 within the range 0.9-1.1%
7. Ensure that the recommended CO_2 level is not exceeded by more than 0.5%
8. Avoid late picking

Annexe - Methods

Harvest evaluation parameters

The evaluation of harvest parameters followed the sequence indicated below:

Internal ethylene concentration (IEC). IEC was measured on five intact undamaged apples from each consignment. A sample of the internal atmosphere of each apple was taken by syringe (0.5ml) and injected into a gas chromatograph fitted with an alumina column and FID detector. Results were expressed as parts per billion (ppb) of ethylene.

Fruit firmness. In the 2000-01 experiment measurements of firmness were carried out using an automated penetrometer fitted with an 11-mm probe. Two measurements were made on the opposite sides of each fruit in a ten-fruit sample. Measurements were made in the equatorial region after removal of the peel. In subsequent years firmness measurements were made using an LRX (Lloyd Instruments) materials testing machine fitted with an 11-mm probe. Firmness was the maximum force (N) recorded during the insertion of the probe to a depth of 8mm. Newtons (N) can be converted to kilograms (kg) by dividing by 9.81.

Soluble solids concentration. Juice was extracted from each apple using a 'Chylofel' (Copa - Technologie S.A.) apparatus and mixed to form a composite sample. Soluble solids concentration (%) was measured using a BRX-242 refractometer (Camlab Ltd).

Internal disorders. Each fruit was cut at the calyx end and at the equator and examined for the presence of disorders. The incidence of each type of disorder was recorded.

Starch test. Half of each apple cut for internal examination was dipped in a solution containing 1% w/v iodine and 4% w/v potassium iodide. Dipped sections were left for at least an hour before being assessed. Each apple was scored (1-slight central discoloration to10-complete discoloration) using the starch conversion chart for apples (circular type) issued by Ctifl. An average score was calculated for each sample.

Post-storage evaluation parameters

Firmness was measured using the method described for samples at harvest.

External disorders. Fruits were examined for the presence of various types of disorders and diseases. The number of fruit affected by each type of disease/disorder was recorded and the incidence was calculated.

Greasiness. The stem end of each apple in a sample was squeezed between the thumb and forefinger. This action generated a sound on apples without greasy skins. Where the skins of apples were greasy it was not possible to generate a sound. On this basis the percentage of greasy fruits was estimated. It is accepted that the method was rather crude in the sense that apples were classified as greasy or not. In reality varying extents of greasiness are observed but an objective assessment of severity is difficult to carry out and was not attempted.

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 four cards that range from green (1) to yellow (4). The average score was calculated for each sample.

Internal disorders. Each fruit was cut at the calyx end and at the equator and examined for the presence of diseases and disorders. Physiological disorders affecting the fruit included breakdown and core flush. The number of fruit affected by each type of disorder was recorded and the incidence was calculated.

