APRC PROJECT REPORT

Project SP122: Low temperature storage of Gala apples

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Background

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 '2nd 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. Although the major objective of the current work is to investigate the prospect of reducing the storage temperature for CA-stored Gala apples the effects of a range of CA conditions, including 8/13, are being evaluated. This 3-year project began in July 2000. This report covers the period from January-June 2001 inclusive.

Year 1 Experimental details

Experimental details were provided in the previous report (report to December 2000) but are given again to provide continuity. On 20 and 21 September 2000 samples of apples were taken from 6 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 4 CA storage treatments (CO_2/ O_2): 5/1, 0/1, 0/2 and 8/13, and 2 storage temperatures: 1.5-2^{o}C and 0-0.5^{o}C. There were 2 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 7 days at 20^{o}C.

Results

<u>Harvest maturity and fruit mineral composition</u>

See the previous report.

Storage quality

Overall effects of temperature

Removal 1

At the first examination in mid-November (55 days) fruit stored at the lower temperature (0-0.5^{o}C) were slightly, but significantly, firmer (Table 1). However, there was no significant effect of storage temperature on the firmness of the fruit after a further 7 days at 20^{o}C (Table 2). Soluble solids content was slightly, but significantly, lower in fruits stored at the lower temperature (Table 3). 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 4). No disorders were evident in the fruit at either temperature (Tables 5-8).

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 1). However, after a further 7 days at 20^{o}C those fruit that had been stored at the lower temperature were firmer (Table 2). The soluble solids concentrations were similar in fruit from both temperatures (Tables 3) but acidity remained higher in fruit from the lower temperature (Table 4). There were no physiological disorders in fruit from either temperature examined immediately after removal (Tables 5 and 7) but a low incidence of breakdown and core flush was recorded in fruit from both temperatures after a further 7 days at 20^{o}C (Tables 6 and 8). 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 1). However, there was a larger benefit of the lower temperature on the firmness of fruit subjected to a further 7 days at 20^{o}C. Those stored at 0-0.5^{o}C were 6.2N (0.6kg) firmer than those stored at the higher (recommended) temperature of 1.5-2^{o}C (Table 2). Fruits stored at the lower temperature were higher in soluble solids and acid concentration (Tables 3 and 4). A low incidence of breakdown and core flush was recorded in fruits examined immediately after storage (Tables 5 and 7) 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 7-day period at 20^{o}C 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 6 and 8).

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 1). After a further 7 days at 20ºC those stored at 0-0.5ºC were 3.5N (0.4kg) firmer than those stored at the higher (recommended) temperature (Table 2). Contrary to the results obtained at the previous removal the soluble solids concentration was higher in fruits stored at the higher temperature (Table 3). There was no effect of storage temperature on acid concentration in the fruit (Table 4). The incidence of breakdown had increased 2-fold in the 25 days between removal 3 and removal 4 (Table 5) 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 7 days at 20ºC (Table 6). A low incidence of core flush was recorded in fruit immediately ex-store but this increased markedly during a further 7 days at 20ºC (Tables 7 and 8). 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 1). However after a further 7 days at 20ºC 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 2). 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 3 and 4). There were no physiological disorders in the fruit immediately ex-store nor after a further 7 days at 20ºC (Tables 5-8).

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 (0/1 and 5/1) were maintaining firmness better than 0/2 and 8/13 (Table 1). The effect was particularly noticeable after a further 7 days at 20ºC (Table 2). 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 3 and 4). There were no physiological disorders in the fruit immediately ex-store (Tables 5 and 7) but breakdown and core flush developed in fruit stored in 8/13 and subjected to a further 7 days at 20ºC (Tables 6 and 8). 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 4 of the 6 orchards (Tables 6-8). 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 (0/1 and 5/1) over 0/2 and 8/13 were marked ex-store but particularly so after a further 7 days at 20^{o}C (Tables 1 and 2). Again there were no effects of CA regimes on soluble solids concentrations (Table 3) but effects on acid concentrations were again significant. The low acid in fruit stored in 8/13 (Table 4) was a possible reaction to the development of breakdown that was restricted to fruit in these conditions (Table 5 and 6). Similarly the development of core flush was restricted primarily to the 8/13 CA condition (Tables 7 and 8).

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 1). There was a 16.7N (1.7kg) difference in firmness between fruit stored in 5/1 and that stored in 0/2. 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, 0/2 early January, 0/1 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 3). Acid concentrations were low in fruit stored in 0/2 and 8/13 compared with the ULO regimes (Table 4). 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 7 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.

Conclusions

It was apparent from the nature of the data for storage disorders that the use of standard statistical techniques was not appropriate. This was due to the fact that the data was 'skewed' i.e. virtually all the disorders occurred in one CA regime (8/13). Other, more appropriate, statistical techniques will be applied to enable testing of temperature and orchard effects on the incidence of disorders.

There was a small but consistent improvement in fruit firmness by storing Gala apples at 0-0.5^{o}C as opposed to 1.5-2^{o}C particularly in fruits stored longer than 106 days and where fruits were subjected to a further 7 days at 20^{o}C.

The effects of temperature were small compared with the effects of the different CA regimes that were tested. 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 over the storage period 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. The lower temperature of storage tended to increase the incidence of core flush but again this was generally relevant to fruit stored too long in the 8/13 regime.

It would be premature to recommend lowering the storage temperature for CA-stored Gala apples on the basis of one year of results. From previous work done on 'chilling-sensitive' cultivars such as Cox and Bramley it is clear that susceptibility to low temperature breakdown is related to seasonal variation in climatic conditions during development.

In year 2 of the project the effect of storage temperatures on fruit quality will be assessed again. The effect harvest date will also be investigated since this is likely to affect any beneficial response to reduced storage temperature and the susceptibility of the fruit to chilling injury.

Table 1. Gala storage trial 2000-01 firmness (N) data, immediately on removal from store. 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.

	Days in store	Firmness (N)						s.e.d. [##]	d.f.
Effects of temperature		°C					Significance of temperature effect		
		0-0.5	1.5-2						
	55	78.0	76.5				*	-	
	106	73.3	72.7				n.s.	-	
	153	69.9	68.3				**	-	
	178	65.6	63.2				***	-	
Effects of CA		CO_2/O_2							
		0/1	0/2	5/1	8/13				
	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
Effects of orchard		Orchard reference							
		Kent W	Kent C	Kent Pe	Kent Pt	E. Ang W	E. Ang L		
	55	80.1	78.1	57.9	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

*, **, *** indicates significant effect of temperature at the 5%, 1% and 0.1% level of probability respectively and non-significant (n.s.) effect. [##] - experiment structure does not provide an s.e.d. for temperature effects.

Table 2. Gala storage trial 2000-01, firmness (N) data after 7 days at 20ºC. 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, after 7 days at 20ºC. 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.

	Days in store	Firmness (N)						s.e.d. ##	d.f.
Effects of temperature		ºC 0-0.5	ºC 1.5-2				Significance of temperature effect		
	55	67.7	67.5				n.s.	-	
	106	68.6	66.4				**	-	
	153	66.9	60.7				***	-	
	178	61.3	57.8				***	-	
Effects of CA		CO_2/O_2 0/1	0/2	5/1	8/13				
	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
Effects of orchard		Orchard reference Kent W	Kent C	Kent Pe	Kent Pt	E. Ang W	E. Ang L		
	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

*, **, *** indicates significant effect of temperature at the 5%, 1% and 0.1% level of probability respectively and non-significant (n.s.) effect. ## - experiment structure does not provide an s.e.d. for temperature effects.

Table 3. Gala storage trial 2000-01, soluble solids (%SS) data immediately on removal from store. 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.

	Days in store	Soluble solids (%SS)						s.e.d. [##]	d.f.
Effects of temperature		°C					Significance of temperature effect		
		0-0.5	1.5-2						
	55	11.8	12.1				*	-	
	106	12.4	12.3				n.s.	-	
	153	12.4	12.1				*	-	
	178	12.0	12.4				**	-	
Effects of CA		CO_2/O_2							
		0/1	0/2	5/1	8/13				
	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
Effects of orchard		Orchard reference							
		Kent W	Kent C	Kent Pe	Kent Pt	E. Ang W	E. Ang L		
	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

*, **, *** indicates significant effect of temperature at the 5%, 1% and 0.1% level of probability respectively and non-significant (n.s.) effect. [##] - experiment structure does not provide an s.e.d. for temperature effects.

Table 4. Gala storage trial 2000-01, titratable acids data after 7 days at 20ºC. 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.

	Days in store	Titratable acids (g malic acid kg^{-1} of juice)						s.e.d. ##	d.f.
Effects of temperature		ºC					Significance of temperature effect		
		0-0.5	1.5-2						
	55	3.7	3.6				**	-	
	106	3.5	3.3				**	-	
	153	3.2	3.1				*	-	
	178	2.9	2.9				n.s.	-	
Effects of CA		CO_2/O_2							
		0/1	0/2	5/1	8/13				
	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
Effects of orchard		Orchard reference							
		Kent W	Kent C	Kent Pe	Kent Pt	E. Ang W	E. Ang L		
	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

*, **, *** indicates significant effect of temperature at the 5%, 1% and 0.1% level of probability respectively and non-significant (n.s.) effect. ## - experiment structure does not provide an s.e.d. for temperature effects.

Table 5. Gala storage trial 2000-01, data for internal breakdown immediately on removal from store. 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.

	Days in store	Internal breakdown (%)					
Effects of temperature		°C					
		0-0.5	1.5-2				
	55	0	0				
	106	0	0				
	153	3.5	3.3				
	178	6.5	8.5				
Effects of CA		CO_2/O_2					
		0/1	0/2	5/1	8/13		
	55	0	0	0	0		
	106	0	0	0	0		
	153	0	0	0	13.8		
	178	0	0	0	30.0		
Effects of orchard		Orchard reference					
		Kent W	Kent C	Kent Pe	Kent Pt	E. Ang W	E. Ang L
	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 6. Gala storage trial 2000-01, data for internal breakdown after 7 days at 20°C. 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 kept for 7 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.

	Days in store	Internal breakdown (%)					
Effects of temperature		°C					
		0-0.5	1.5-2				
	55	0	0				
	106	2.1	0.4				
	153	10.8	14.6				
	178	16.9	19.6				
Effects of CA		CO_2/O_2					
		0/1	0/2	5/1	8/13		
	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		
Effects of orchard		Orchard reference					
		Kent W	Kent C	Kent Pe	Kent Pt	E. Ang W	E. Ang L
	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 7. Gala storage trial 2000-01, core flush data immediately on removal from store. 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.

	Days in store	Core flush (%)	
Effects of temperature		°C	
		0-0.5	1.5-2
	55	0	0
	106	0	0
	153	0.21	0.21
	178	2.29	1.46

Effects of CA		CO_2/O_2			
		0/1	0/2	5/1	8/13
	55	0	0	0	0
	106	0	0	0	0
	153	0	0	0	0.83
	178	0	0	1.25	6.25

Effects of orchard		Orchard reference					
		Kent W	Kent C	Kent Pe	Kent Pt	E. Ang W	E. Ang L
	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 8. Gala storage trial 2000-01, core flush data after 7 days at 20ºC. 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 7 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.

	Days in store	Core flush data (%)					
Effects of temperature		ºC					
		0-0.5	1.5-2				
	55	0	0				
	106	4.17	1.88				
	153	8.54	6.87				
	178	18.5	15.8				
Effects of CA		CO_2/O_2					
		0/1	0/2	5/1	8/13		
	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		
Effects of orchard		Orchard reference					
		Kent W	Kent C	Kent Pe	Kent Pt	E. Ang W	E. Ang L
	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