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Project leader:	Richard Colgan, Produce Quality Centre (PQC), Natural Resources Institute (NRI), University of Greenwich
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Industry Representative:	Nigel Jenner, Norman Collett Ltd.
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[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

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

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GROWER SUMMARY

Headline

- The best controlled atmosphere regimes have been identified for storing Gala through to April and June.

Background and expected deliverables

UK production of Gala is expected to increase by 40% over the next three to four years. To provide a market for this fruit there is a need to extend the marketing period of UK Gala into April/ May. The challenge facing growers storing Gala beyond late March/early April is to compete with new season imports from the Southern hemisphere which are perceived to have superior quality at this stage of the season.

For Gala a number of storage regimes are currently being used; a regime of <1% CO_2, 1% O_2 at 0.5°C will allow storage up to February. Extending storage into March or early April requires the use of 5% CO_2, 1% O_2 at 1.5°C to prevent the development of scald and loss of firmness during shelf-life. There have been several reports that after long-term controlled atmosphere (CA) storage Gala apples have less flavour, relating to a decrease in flavour volatiles. Low oxygen concentrations and high carbon dioxide concentrations both contribute to this effect. Work funded by APRC (Stow and Genge, 2000) looking at storage in a range of CO_2 (0, 2.5 and 5% CO_2) and O_2 (1, 1.5 and 2%) conditions reported that flavour production in general declined after 110 days of storage, and that where CO_2 was present in the atmosphere, flavour volatile production was suppressed. The highest flavour production was reported at the highest oxygen concentration tested (2%).

With the advent of alternative strategies to reduce softening and control scald synthesis (SmartFresh™, ethylene scrubbing, ultra-low oxygen storage such as used with dynamic controlled atmosphere - DCA technologies), the need to incorporate 5% CO_2 in the storage atmosphere may be avoided or at least reduced for longer term storage. It is now vital that we define the best storage regimes for long-term storage of UK Gala where flavour production can be maintained for longer.

There have been many studies to identify volatiles in terms of their contribution to apple flavour. Methods for volatile capture by Solid Phase Micro extraction (SPME), or Thermal Desorption techniques followed by analysis using Gas Chromatograph with Mass spectroscopy (GC-MS) are currently under investigation at NRI.

A number of studies have charted the fall in volatile production during CA and air storage, and, as mentioned above, it is well documented that CA storage suppresses production of flavour production with time. However, some studies (Stow and Genge, 2000; Plotto *et al.,*

1999) have found a poor correlation between ester flavour volatile decline and taste panel assessments of good eating quality, which suggests other attributes such as sweetness, acidity and texture (crispness) are also essential for the overall sensory perception of fruit quality. This underlines the importance of including the full range of characteristics in any assessment of eating quality of flavour

This project seeks to define a practical protocol for assessing Gala flavour that can be used to optimise pre and postharvest practices to maintain flavour, whilst identifying orchards with fruit suitable for long-term storage. A preliminary study will be undertaken on the effects of picking date, storage regime and SmartFresh™ application on the flavour retention of long-term stored fruit.

Summary of the project and main conclusions

Gala from six orchards (A-F) across Kent were harvested on two picking dates (8/9th and 12/13th September 2014). The rapidly changing maturity of Gala in the 2014 season resulted in Picks 1 and 2 being harvested only three to four days apart. Fruits were cooled for 24 hours to store holding temperature (1.5°C or 0.5°C) and a subset of samples were treated with SmartFresh™ (625 ppb) for 24 hours before atmospheres were exhausted. Controlled atmosphere regimes were established by automatic injection of nitrogen to reach 1% O_2. In addition to the AHDB-funded CA regime trial, International Controlled Atmosphere ltd (ICA) funded additional treatments (3% CO_2, 0.8,.0.6 and 0.4% O_2) Where Gala was stored below 1% O_2, fruit was held at 1% O_2 for a week before re-establishing conditions of 0.8, 0.6.or 0.4% O_2 by fruit respiration. CO_2 was added by automatic injection during the initial CA pull down phase. The CA regimes assessed are detailed below in the Table 1.

Table 1. Controlled Atmosphere, Temperature and SmartFresh treatments

Funder	Treatment	CA regime	Temp	Pick	SmartFresh
AHDB	T1	5%CO2, 1%O2	1.5°C	Pick 1	SF
AHDB	T2	5%CO2, 1%O2	1.5°C	Pick 1	
AHDB	T3	5%CO2, 1%O2	0.5°C	Pick 1	SF
AHDB	T4	5%CO2, 1%O2	0.5°C	Pick 1	
AHDB	T5	3%CO2, 2 %O2	0.5°C	Pick 1	SF
AHDB	T6	5%CO2, 0.4 %O2	0.5°C	Pick 1	
ICA	T7	3%CO2, 0.8%O2	0.5°C	Pick 1	
ICA	T8	3%CO2, 0.6 %O2	0.5°C	Pick 1	
ICA	T9	3%CO2, 0.4%O2	0.5°C	Pick 1	
AHDB	T10	5%CO2, 1%O2	0.5°C	Pick 2	SF
AHDB	T11	3%CO2, 2%O2	0.5°C	Pick 2	SF

Harvest Maturity

In 2014, changes in Gala harvest maturity progressed rapidly. Fruit firmness in Pick 1 ranged from 8.6-10.2 kg, but dropped to 7.8-9.5 kg in the second pick only four days later. Internal ethylene concentrations in fruit from orchards A, D, E and F increased rapidly between the two picks (Table 2). Fruit respiration by the second pick had increased significantly between the two picks and starch profiles of fruit at harvest ranged from 76-90% for Pick 1 and 85% to 63 % by Pick 2. In orchards A, D, E and F, starch loss increased over the four day period between picks in line with increased internal ethylene production. Dry matter content in orchards sampled in Pick 1 ranged from 12.2% to 15.6%. A similar profile of dry matter was recorded in fruit from the second pick.

Table 2. Harvest maturity measurements of 6 Gala orchards Harvested on the 8/9th and 12/13th September 2014

		Firmness	% Brix	Starch	Internal ethylene	Dry Matter	Respiration
Pick	Orchard	N		Ctifl (%)	(ppb)	%	ml-kg-h^{-1}
1	A	8.4	9.9	4.7 (75.7 %)	392.1	12.2	0.57
1	B	8.9	10.9	3.8 (74.8 %)	222.9	14.6	0.79
1	C	9.8	11.6	3.1(87.4 %)	430.3	15.6	0.84
1	D	9.0	11.0	3.6 (84.4 %)	328.0	15.0	0.90
1	E	8.3	10.9	4.3 (79.3 %)	202.3	14.0	0.79
1	F	8.9	10.6	2.6 (91.6%)	162.0	13.7	0.68
2	A	7.5	10.6	7.4 (56.6 %)	1025.7	12.7	1.73
2	B	8.9	11.2	3.5 (85 %)	101.9	14.7	1.73
2	C	9.1	12.0	3.7 (83.5 %)	398.7	16.1	2.17
2	D	8.6	11.8	4.9 (73.9 %)	637.8	15.5	2.24
2	E	8.1	11.6	5.9 (69.6 %)	574.9	14.4	2.80
2	F	8.4	10.9	4.9 (73.9%)	416.1	13.9	1.81

Storage trials

Apples from each orchard were randomly placed into grey plastic crates with damaged and misshapen fruits discarded. Apples were cooled to store temperature 1.5 or 0.5°C within 24 hours. SmartFresh^{TM} (625 ppb) was applied to selected treatments for 24 hours before exhausting the cabinets. CA regimes of 5% CO_2 and 1% O_2 or 3% CO_2 and 2% O_2 were established immediately by injection of nitrogen and CO_2. Where treatments involved O_2 concentrations below 1%, CA regimes were adjusted to either 5% or 3% CO_2 and 1% O_2 for 7 days by manual adjustment, before allowing O_2 to drop to the set point by fruit respiration.

Quality Assessment, volatile collection and analysis: April/June

Fruit samples were sent to technologists and advisors in a number of Producer Organisations and allied industries. Gala from each orchard x storage regime combination was tasted by at least six people, with a total of 96 fruit being sent to each organisation for tasting by a panel of people.

Gala samples were simultaneously assessed for fruit firmness and % Brix. Juice samples were collected and frozen (-20°C) for acid analysis by HPLC and inspected for external and internal disorders. Gala samples for volatile analysis were taken from store and placed in shelf-life conditions (18°C) for 48 hours. Samples of six fruits were cut into four quarters and placed inside air-tight 5L glass jars. Volatiles were collected using porapack columns. After sampling, columns were sealed and wrapped in aluminium foil, and stored at 4.5°C before analysis.

Results

First assessment – April 2015

For the purposes of identifying the optimum CA regime required for maintaining the quality of Gala into April, data from Orchard A was excluded from the analysis, due to significant internal breakdown. Taste panel assessment of overall acceptability averaged across 5 orchards ranged from 5.3-6.1 (Table 3). Fruit stored in 5/1 at 1.5°C or 5/1 at 0.5°C + SF produced fruit with an overall acceptability similar to imported fruit in April (6-6.1). There was no clear distinction between the optimum storage temperature and the effect of SF in the April assessment. It is important to note that CA's in this trial were generated within 24 hours of fruit reaching store temperature using nitrogen flushing and CO_2 injection. Rapid establishment of CA for Gala has the potential to improve ex-store quality of the fruit in long-term storage.

Table 3. Taste panel results April 2015- data averaged across five orchards

CA regime	Temperature	SmartFresh	Overall Acceptability	Aroma	Flavour	Sweetness	Acidity	Firmness
imported 2	n/a		6.1	5.2	5.7	5.6	3.2	6.9
5%CO2, 1%O2	1.5°C	-SF	6.1	5.3	5.6	5.4	3.9	7.1
imported 1	n/a		6.0	5.4	5.8	5.9	3.1	7.4
5%CO2, 1%O2	0.5°C	+SF	6.0	5.0	5.5	5.6	3.6	7.4
3%CO2, 0.4%O2	0.5°C	-SF	6.0	5.4	5.4	5.4	3.5	7.5
3%CO2, 2%O2	0.5°C	+SF	5.6	5.1	5.3	5.4	3.9	7.3
3%CO2, 0.6 %O2	0.5°C	-SF	5.6	5.4	5.4	5.3	4.1	7.2
3%CO2, 2 %O2	0.5°C	+SF	5.5	5.0	5.1	5.2	3.7	7.5
3%CO2, 0.8%O2	0.5°C	-SF	5.5	5.4	5.2	5.2	4.2	7.1
5%CO2, 1%O2	1.5°C	+SF	5.4	4.7	5.0	4.8	3.7	7.2
5%CO2, 0.4 %O2	0.5°C	-SF	5.4	5.4	4.9	5.5	3.4	7.0
5%CO2, 1%O2	0.5°C	+SF	5.3	4.3	5.2	5.2	3.7	6.9
5%CO2, 1%O2	0.5°C	-SF	5.3	4.9	5.1	5.2	3.9	7.0

In comparing firmness, % Brix, acidity and flavour profiles of Gala samples in April, it was found that UK Gala was over 2 kg firmer than imported fruit at the beginning of the Southern Hemisphere season (Table 4). Southern Hemisphere fruit in April had a higher acetate ester profile providing a 'fruity' aroma to apples with approximately 10 fold higher content of 2-methylbutyl acetate, 15-20 fold higher hexyl acetate and 4 fold increase in butyl acetate. However, UK Gala was firmer and had a higher background acidity after seven months storage. This in part countered the lower volatile profiles and emphasises the importance of texture and acid/sugar profile when considering overall acceptability (Table 4).

A new DCA monitored regime of 3% CO_2 and 0.4% O_2 produced fruit with taste panel overall acceptability scores of 6.0 in April when averaged over 5 orchards. The quality of fruit was equal to imported Gala and Gala stored in 5/1 regimes.

Taste panel assessment of individual orchard consignments in CA regimes

When the storage behaviour of individual orchard consignments was examined under different CA regimes, Gala stored in 5% CO_2, 1% O_2 (1.5°C) without SmartFresh and 5% CO_2,1% O_2 (0.5°C) with SmartFresh provided the highest number of orchard consignments where overall acceptability equalled imported fruit (Table 4). Gala from orchard C stored in 3% CO_2 and 0.8% O_2 produced the highest overall acceptable scores (6.7) of all fruit tasted (Table 4). Gala from orchard C was the highest ranked orchard providing fruit with the best overall eating acceptability scores and yielded the highest number of consignments (5/15) where acceptability scores were equal or exceeded the scores (5.9-6.6) recorded for imported fruit. Gala from this orchard (Mondial) had the highest dry matter content and % Brix at harvest and was the orchard where fruit was consistently ranked with the highest concentration of volatiles.

Table 4. Individual treatment x orchard combinations producing fruit with an overall eating quality equal to or exceeding imported Gala in April 2015

Pick	Storage atmosphere	Temp.	SF?	Orchard	Overall acceptability	SE
1	3%CO2, 0.8%O2	0.5°C	-SF	C	6.7	0.4
1	5%CO2, 1%O2	1.5°C	-SF	E	6.6	0.6
imported 2					6.6	0.4
1	5%CO2, 1%O2	1.5°C	-SF	B	6.5	0.6
1	5%CO2, 1%O2	0.5°C	+SF	F	6.5	0.5
1	3%CO2, 2 %O2	0.5°C	+SF	D	6.3	0.7
1	3%CO2, 0.6 %O2	0.5°C	-SF	C	6.3	0.7
1	5%CO2, 1%O2	1.5°C	-SF	F	6.2	0.7
2	3%CO2, 2%O2	0.5°C	+SF	D	6.1	0.6
1	5%CO2, 1%O2	0.5°C	+SF	C	6.1	0.8
1	3%CO2, 0.6 %O2	0.5°C	-SF	E	6.1	0.7
1	5%CO2, 0.4 %O2	0.5°C	-SF	C	6	0.8
1	5%CO2, 1%O2	0.5°C	+SF	B	6	0.7
1	5%CO2, 1%O2	0.5°C	+SF	C	6	0.4
imported 1					5.9	0.6

Compositional and flavour profiles of Gala orchard consignments- April

Overall, orchard C provided fruit with the highest firmness values (92.9 N). The fruit had softened by only 5 N (~0.5 kg) since harvest (Table 5). Orchard C (Mondial Gala) contained the highest dry matter content over both picks (15.6%-16.1%) and % Brix in fruit sampled in April (13.4%) and was equal to the consignment of imported Gala. Imported Gala was 20 N (2 kg) softer than UK Gala stored for 7 months under CA conditions. Malic acid, the major contributor to fruit acidity, was significantly higher in 4 out of 6 Gala orchards compared to imported Gala. Comparison of major volatile components of Gala flavour showed imported fruit to have a higher acetate volatile profile, with significantly higher 2-butyl-acetate (ripe banana), amyl acetate, hexyl acetate (pear/banana flavour), compared to UK Gala in April, providing fruit with distinctive Gala apple flavour (Table 5). Moreover, imported fruit had a higher content of hexanol which provides sharp 'fusel' note to apple flavour. Hexanol is readily converted (esterified) into hexyl acetate. The conversion of hexanol to hexyl acetate is suppressed by high CO_2 in the storage atmosphere. Despite the difference in volatile aroma profiles, the overall acceptability scores of UK fruit in some cases was equal to imported fruit based on better texture and higher ratios of acidity to sugar content. Butyrate esters were low across all orchard and imported fruit. The hexanal content of orchards B, C and E were higher than imported fruit. This compound is often associated with green- unripe flavour. A more extensive profile of volatiles can be found in the science section.

Table 5. The overall effect of orchard consignments on quality attributes and major volatiles of Gala (averaged across all CA regimes) April 2015.

Orchard	A	B	C	D	F	G	Imported	**Fprob**	**$LSD_{0.05}$**
Firmness (kg)	7.5	8.7	**9.3**	**9.0**	8.3	8.6	6.7	**<.001**	**1.37**
% Brix	10.7	12.5	**13.4**	12.7	12.3	12.2	**13.4**	**<.001**	**0.24**
Malic acid (µL/µL)	4.5	**6.3**	**5.2**	**6.4**	**5.7**	4.8	4.9	**<.001**	**0.30**
Acetate esters									
isobutyl acetate	1.6	2.1	2.3	3.5	2.2	2.1	**30.0**	**0.392**	**1.75**
Amyl acetate	0.05	0.07	0.08	**0.23**	0.05	0.06	**5.12**	**0.537**	**0.22**
Hexyl acetate	1.08	1.27	1.53	**2.39**	1.29	1.33	**36.89**	**0.627**	**1.58**
Aldehyde									
Hexanal	19.3	**25.2**	**25.5**	23.0	21.7	**25.8**	14.7	**<.001**	**3.01**
2-Hexonal	4.9	**6.1**	**6.4**	5.6	5.7	**6.1**	**8.8**	**0.081**	**1.08**
Alcohols									
Hexanol	2.8	3.2	3.7	2.8	3.2	3.2	**6.3**	**0.09**	**0.66**

The effect of CA regime on composition and flavour profile

Evaluation of CA regimes averaged across all orchards found that early harvested Gala (Pick 1) stored in 5/1 regime at 1.5°C and treated with SF provided the firmness fruit in April (Table 6). % Brix during storage was not affected by CA regime, temperature or SF. However, malic acid content was higher in Pick 2 fruit stored in 5/1 or 3/2 (Table 6) and early picked fruit stored under the DCA regime (5% CO_2 and 0.4% O_2). Moreover, fruit stored in 3/2 treated with SF provided fruit with higher apple volatile esters: isobutyl, amyl and hexyl acetate. Overall, orchard effect had a bigger influence than storage regime on ex-store quality in April (Table 6).

Table 6. The overall effect of CA regime on quality attributes and major volatiles of Gala (averaged across 5 orchards- excluding Orchard A) April 2015.

CA Regime (% CO_2/% O_2)	5/1	5/1	5/1	5/1	5/0.4	5/1	3/2		
Storage Temperature	1.5°C	1.5°C	0.5°C	0.5°C	0.5°C	0.5°C	0.5°C		
Pick (+/-SmartFresh)	1(+)	1(-)	1(+)	1(-)	1(-)	2(+)	2(+)	Fprob	$LSD_{0.05}$
Firmness (kg)	**8.9**	8.7	8.6	8.4	8.7	8.3	8.5	**<.001**	**1.851**
% Brix	12.5	12.3	12.1	12.4	12.2	12.5	12.5	**0.065**	**0.325**
Malic acid µL/µL	5.8	5.7	5.8	5.0	**6.5**	**6.4**	**6.6**	**<.001**	**0.407**
Acetate ester									
Isobutyl acetate	1.7	1.9	1.9	2.2	2.5	2.1	1.8	**0.364**	**2.36**
Amyl acetate	0.03	0.04	0.08	0.07	0.07	0.06	0.05	**0.377**	**0.29**
Hexyl acetate	1.21	1.05	1.35	1.45	1.44	1.15	1.03	**0.439**	**2.14**
Aldehyde									
Hexanal	24.0	21.5	20.8	23.3	24.0	24.6	21.4	**0.067**	**4.07**
2-hexonal	5.9	5.1	5.0	6.5	6.6	5.9	4.7	**0.045**	**1.46**
Alcohol									
Hexanol	3.2	2.6	2.9	**3.7**	**3.8**	2.9	2.6	**0.038**	**0.89**

Table 6-continued The overall effect of CA regime on quality attributes and major volatiles of Gala (averaged across 5 orchards- excluding Orchard A) April 2015.

CA Regime (CO_2/O_2)	3/2	3/0.8	3/0.6	3/0.4		
Temperature	0.5°C	0.5°C	0.5°C	0.5°C	Fprob	$LSD_{0.05}$
Pick (+/-SmartFresh™)	1(+)	1(-)	1(-)	1(-)		
Firmness (kg)	8.6	8.6	8.4	8.5	**<.001**	1.851
% Brix	12.3	12.3	12.1	12.2	**0.065**	0.3253
Malic acid µL/µL	4.7	4.6	4.5	4.9	**<.001**	0.4075
Acetate ester						
isobutyl acetate	**4.9**	2.1	2.4	2.0	**0.364**	2.36
Amyl acetate	**0.41**	0.07	0.07	0.05	**0.377**	0.29
Hexyl acetate	**3.74**	1.35	1.34	1.18	**0.439**	2.14
Aldehyde						
Hexanal	21.1	**26.6**	25.6	24.8	**0.067**	4.07
2-Hexonal	5.3	6.9	5.5	6.4	**0.045**	1.46
Alcohol						
Hexanol	2.9	**3.7**	3.0	**3.6**	**0.038**	0.89

Second Assessment- June 2015

Taste panel assessment

In general, the overall acceptability scores for UK Gala dropped slightly from April to June, with only one UK sample exceeding a score of 6. The highest ranking imported Gala in June produced an overall acceptability score of 7.3. SF-treated Gala stored in 3/2 (0.5°C) from Picks 1 and 2 were the most favoured UK Gala with overall acceptability scores of 6.2 and 5.8 respectively. Interestingly, Gala stored in DCA regimes where oxygen was lowered to between 0.6-.0.4% and 3-5% CO_2 was the next most favoured fruit. In general, taste panel perception of sweetness and flavour were the two attributes that most correlated with perception of overall acceptability, while poor texture and a lack of acidity experienced with imported 2 Gala led to low overall acceptability scores (Table 7).

Table 7. Taste Panel assessment of UK stored and imported Gala: June 2015

CA/Temp/SF/Pick	Overall Acceptability	Aroma	Flavour	Sweetness	Acidity	Firmness	Crispness
imported 1	7.3	5.6	6.1	6.0	4.0	7.0	6.8
3/2, 0.5°C, SF, P1	6.2	5.4	5.7	5.3	4.4	7.3	7.3
3/2, 0.5°C, SF, P2	5.8	4.7	5.0	5.2	4.4	7.0	7.0
5/0.4, 0.5°C P1	5.7	5.0	5.3	4.9	4.9	7.0	7.1
3/0.6, 0.5°C P1	5.6	4.6	5.1	4.8	4.6	6.9	6.7
3/0.4, 0.5°C P1	5.6	5.0	5.5	5.3	4.3	6.7	6.9
5/1, 0.5°C, SF P1	5.5	4.8	4.8	4.9	4.3	7.1	6.9
5/1, 1.5°C, SF P1	5.5	4.5	4.9	4.9	4.4	7.0	6.8
3/0.8, 0.5°C P1	5.4	4.9	4.9	4.8	4.2	6.9	6.7
5/1, 0.5°C, SF P1	5.4	4.4	4.9	4.6	4.0	7.0	6.9
5/1, 0.5°C P1	5.3	4.3	4.6	5.0	4.3	6.9	6.9
5/1, 1.5°C P1	5.2	4.7	4.8	4.9	4.5	7.1	7.1
imported 2	4.1	4.3	5.0	6.3	1.9	3.0	3.1

The poor firmness rating of the second batch of imported Gala fruit was confirmed by penetrometer readings of 49.9 N. Interestingly, the most preferred batch of imported fruit firmness measured only 58.5 N but was perceived to have ample firmness and crispness in the taste panel assessment and was considered equal to UK Gala where firmness ranged from 71.8-91.9N.

Gala from orchard C maintained high % Brix in CA storage until June and was sweeter than imported fruit (Table 8). Malic acid concentrations in imported fruit were generally low while UK Gala from 3 orchards maintained significantly higher acid profiles despite the length of CA storage. In terms of flavour production, imported fruit was higher in the acetate esters isobutyl acetate and hexyl acetate, but lower in 2-methylbutyl acetate (Table 8). Moreover, imported fruit had higher undecanal which produces a fatty citrus waxy-floral refreshing flavour bouquet, but significantly lower content of hexanal which is responsible for green- unripe flavours

Table 8. Quality assessment and volatile profile of UK Gala June 2015

Orchard	A	B	C	D	E	F	Import 1	Import 2	Fprob	LSD
Firmness (kg)	7.2	8.5	**9.2**	**8.9**	8.1	8.4	5.8	5.0	**<.001**	1.397
% Brix	10.2	12.4	**13.5**	12.6	12.1	12.0	12.6	12.9	**<.001**	0.150
Malic acid **($\mu g\ \mu L^{-1}$)**	5.2	**6.8**	5.6	**7.1**	**6.4**	5.4	5.3	4.4	<.001	0.282
Acetate esters(ng $g^{-1}h^{-1}$)										
Isobutyl acetate	2.5	8.1	8.1	5.9	4.7	5.5	**11.8**	**14.8**	0.455	6.158
2-Methylbutyl acetate	1.70	3.70	9.10	7.20	4.00	3.00	0.02	0.01	0.289	7.000
Hexyl acetate	0.19	0.56	0.59	0.45	0.54	0.61	1.86	2.41	**0.038**	0.277
Amyl acetate	0.02	0.03	0.19	0.07	0.02	0.02	0.21	0.01	0.441	0.195
Aldehydes										
Undecanal	0.14	0.41	0.43	0.49	0.16	0.02	**41.02**	**43.34**	0.131	0.407
Hexanal	23.30	41.10	**44.40**	38.20	30.90	31.90	0.91	0.97	**0.001**	10.270
Alcohols										
Hexanol	1.93	4.07	**4.88**	3.73	3.57	3.35	2.56	3.99	**0.013**	1.551
Alkanes										
Undecane	0.05	0.04	**0.08**	0.04	0.05	0.04	0.01	0.02	**0.017**	0.014

The effect of CA regime on fruit composition and flavour

The effect of CA regime on composition and volatile profile in fruit coming out of store in June was minimal (Table 9). Pick 1 fruit stored in 5/1 at 1.5°C with SF retained the highest firmness (87.1 N). Storage at 0.5°C did not improve firmness retention or acidity. Acidity retention was improved in early harvested fruit. Fruit stored in 3% CO_2, 2% O_2 with SF was generally considered to have better eating quality in June despite firmness and volatile profiles being non distinguishable from the other CA regimes. In general, fruit volatile profiles were similar for Gala stored in the CA regimes under test, with the exception of Gala stored under Dynamic CA regime of 3% CO_2, 0.8% O_2 where higher concentrations of 2-methylbutyl acetate (fruity, apple flavour) a volatile considered important in imparting characteristic ‘Gala- apple flavour’ was recorded. Fruit stored in 3% CO_2, 0.6% O_2 was higher in hexanal- which imparts ‘green apple flavour’. A more extensive list of volatiles is detailed in the science section.

In these experiments, Gala CA regimes were established using nitrogen flushing and CO_2 injection; more pronounced differences in firmness and compositional analysis may be observed between temperature regimes where CA regimes are established through fruit respiration.

Table 9. Quality attributes and volatile profiles of Gala apples stored for 9 months (June) under a range of CA regimes

CA Regime (% CO_2/% O_2)	5/1	5/1	5/1	5/1	3/0.4	5/1	3/2		
Storage Temperature	1.5°C	1.5°C	0.5°C	0.5°C	0.5°C	0.5°C	0.5°C		
Pick (+/- SmartFresh™)	1(+)	1(-)	1(+)	1(-)	1(-)	2(-)	2(-)	Fprob	$LSD_{0.05}$
Firmness (kg)	**8.7**	8.5	8.4	8.2	8.3	8.2	8.3	**<.001**	**1.891**
%Brix	**12.34**	12.22	11.89	12.12	12.07	12.22	12.10	**<.001**	**0.203**
Malic acid	**6.10**	5.46	4.98	5.06	**6.43**	5.71	5.56	**<0.01**	**0.328**
Acetate esters									
Isobutyl acetate	10.21	7.12	8.40	0.43	5.59	3.46	7.16	**0.274**	**8.338**
2-Methylbutyl acetate	2.90	4.70	2.50	3.90	4.50	3.50	2.50	**0.052**	**9.480**
Amyl acetate	0.02	0.03	0.04	0.06	0.03	0.02	0.01	**0.253**	**0.264**
Hexyl acetate	0.49	0.61	0.39	0.33	0.30	0.76	0.68	**0.215**	**0.375**
Aldehydes									
Hexanal	34.80	37.30	36.80	39.40	37.80	29.90	26.90	**0.313**	**13.910**

Table 9 continued. Quality attributes and volatile profiles of Gala apples stored for 9 months (June 2015) under a range of CA regimes

CA Regime (CO_2/O_2)	3/2	3/0.8	3/0.6	3/0.4		
Temperature	0.5°C	0.5°C	0.5°C	0.5°C	**Fprob**	**$LSD_{0.05}$**
Pick (+/-SmartFresh™)	1(+)	1(-)	1(-)	1(-)		
Firmness (kg)	8.4	8.5	8.2	8.4	**<.001**	**1.891**
%Brix	11.92	12.28	12.12	12.08	**<.001**	**0.203**
Malic Acid	6.78	6.80	7.35	6.55	**<.001**	**0.328**
Acetate ester						
Isobutyl acetate	4.01	1.13	10.30	5.87	**0.274**	**8.338**
2-Methylbutyl acetate	1.90	**18.70**	3.50	4.00	**0.052**	**9.480**
Amyl acetate	0.02	0.38	0.02	0.02	**0.253**	**0.264**
Hexyl acetate	0.43	0.64	0.38	0.40	**0.215**	**0.375**
Aldehydes						
Hexanal	29.20	33.10	**46.10**	33.20	**0.313**	**13.910**

The interaction of orchard consignments in CA regimes

The quality and volatile profile of individual orchard consignments in each treatment that equalled or exceeded taste panel scores of 5.9 were compared with profiles of imported fruit (Table 10). A comparison of compositional analysis between consignments of Gala found no significant increase in firmness, % Brix, acidity or flavour profiles between the imported fruit and highest ranking UK Gala, even though the imported fruit was considered more acceptable.

In many cases, Gala from orchard C fruit had higher 2-methylbutyl acetate, a major component of Gala flavour, compared to other consignments. Due to the nature in which consignments were selected, there was a skew in the number of observations per orchard.

Table 10. Quality attributes and volatile profiles of orchard consignments that equalled or exceeded acceptability scores of 5.9 compared with imported fruit (June)

	Orchard B	Orchard C	Orchard D	Orchard E	Orchard F	Imported 1	Imported 2
Mean Overall Acceptability	6	6.4	6.2	6.2	6.2	7.1	4.1
Firmness (kg)	8.5	**9.2**	9.0	8.1	8.3	5.5	5.0
%Brix	12.3	13.5	12.2	12.1	11.8	12.4	12.6
Malic acid	**6.8**	5.6	**7.1**	**6.4**	5.4	5.3	4.4
Acetates							
Isobutyl acetate	3.79	**7.89**	**7.14**	3.49	**11.81**	**7.48**	**11.87**
Amyl acetate	0.02	**0.25**	0.03	0.01	0.02	0.01	0.03
2-Methylbutyl acetate	2.67	**11.11**	2.45	3.40	1.86	2.46	3.00
Hexyl acetate	0.73	0.49	0.33	0.66	0.21	0.42	0.43
2-Hexenyl acetate	0.07	0.42	0.80	0.22	0.02	0.40	0.38
Alcohols							
Hexanol	3.97	5.39	3.85	3.52	2.22	3.28	4.00
Aldehydes							
Hexanal	29.37	**43.13**	37.40	29.58	33.20	34.81	35.97
Undecanal	0.01	0.52	1.09	0.29	0.03	0.46	0.49
Substituted benzenes							
1,3-Diethylbenzene	0.71	**5.57**	0.35	0.25	0.44	0.47	0.51
Alkanes							
Dodecane	0.08	**1.23**	0.15	0.11	0.13	0.12	0.17
Hexadecane	1.96	**6.97**	2.80	1.99	2.24	1.90	2.94
Hexyl hexanoate	0.02	0.03	0.04	0.02	0.01	0.03	0.03
Nº of observations	3	8	2	3	1	1	1

Financial benefits

Some UK orchards are capable of producing fruit that maintains good eating quality in April and through to June, which is comparable with imported fruit. This could provide an additional marketing window for UK Gala.

Action points for growers

- Early harvesting and rapid establishment of CA conditions can help to maintain fruit quality into April and in some cases through to June.

- Orchards with high dry matter content (15.5-17%) generally produce fruit with better sweetness and firmness and are considered to have better eating quality and are more likely to maintain eating quality for longer

- The CA regimes of 5/1 (1.5°C) without SF and 5/1 (0.5°C) with SF and the DCA regime of 3% CO_2 and 0.4% O_2, provided fruit with the best eating quality in April which was as good as imported Gala.

- The CA regimes of 3% CO2 and 2% O2 + SF and the DCA regime 5% CO2 and 0.4% O2 were the highest ranked CA regimes for maintaining quality through to June.

SCIENCE SECTION

Introduction

UK production of Gala is expected to increase by 40% over the next four years. To provide a market for this fruit there is a need to extend the marketing period of UK Gala into April/ May. The challenge facing growers storing Gala beyond late March/early April is to compete with new season imports from the Southern hemisphere which are perceived to have superior quality at this stage of the season.

For Gala a number of storage regimes are currently being used; a regime of <1% CO_2, 1% O_2 at 0.5°C will allow storage up to February. Extending storage into March or early April requires the use of 5% CO_2, 1% O_2 at 1.5°C to prevent the development of scald and loss of firmness during shelf-life. There have been several reports that after long-term controlled atmosphere (CA) storage Gala apples have less flavour, relating to a decrease in flavour volatiles (Plotto *et al*. 2000, Stow and Genge, 2000). Low oxygen concentrations and high carbon dioxide concentrations contribute to this effect. Work funded by APRC (Stow and Genge, 2000) looking at storage in a range of CO_2 (0, 2.5 and 5% CO_2) and O_2 (1, 1.5 and 2%) conditions reported that flavour production in general declined after 110 days of storage, and that where CO_2 was present, flavour volatile production was suppressed, the highest flavour production was reported in 2% oxygen.

With the advent of alternative strategies to reduce softening and control scald synthesis (SmartFresh^{TM} (SF), ethylene scrubbing, ultra-low oxygen storage such as used with dynamic controlled atmosphere (DCA) technologies), the need to incorporate 5% CO_2 in the storage atmosphere may be avoided or at least reduced for longer term storage. Nonetheless, the suppression of ethylene synthesis/perception and low O_2/high CO_2 storage can reduce the synthesis of precursors of flavour volatile production. Definition of the best storage regimes for long-term storage of Gala where flavour production can be maintained for longer are vital for the UK Gala apple growers.

There have been many studies to identify volatiles in terms of their contribution to apple flavour. Studies in the US and New Zealand have identified the major components of fruity attributes associated with apple; hexyl acetate, butyl acetate and 2-methylbutyl acetate, have been identified as the primary volatiles responsible for apple aroma in several cultivars including Gala. Hexyl acetate was the volatile contributing most to apple fruity and pear flavour and is a major component of the volatiles produced by Gala, but also one of the three most important in the perception of flavour by sensory panellists (Young *et al*. 1996; Plotto 1999). A number of studies have charted the fall in volatile production during CA and air storage, and, as mentioned above, it is well documented that CA storage suppresses production of flavour production with time. Hexyl acetate production is suppressed by elevated CO_2 in the atmosphere but responds well to increasing concentration of O_2 (Stow and Genge, 2000), increasing O_2 from 1 to 2% doubled the amount of hexyl acetate. Other volatiles such as 2-methylbutyl acetate, methyl-2-methylbutyrate, ethyl 2 methylbutyrate and propyl-2- methylbutyrate are also associated with Gala flavour. These all appear to decline during storage. These ester aromas may be important for general fruity and sweet aromas. Additionally, each volatile has odour detection thresholds, whereby small changes in volatiles concentration can have a large impact on overall flavour perception

Some studies (Stow and Genge, 2000; Plotto *et al.,* 1999) have found a poor correlation between ester flavour volatile decline and taste panel assessments of good eating quality, which suggests other attributes such as sweetness and acidity and texture (crispness) are also essential for the overall sensory perception of fruit quality. This underlines the importance of including the full range of characteristics in any assessment of eating quality of flavour

Phase I of the project (TF 213) compared different methods for volatile capture by Solid Phase Micro extraction (SPME), Thermal Desorption, or capture on porpak columns techniques using whole and cut fruit were followed by analysis using Gas Chromatograph with Mass spectroscopy (GC-MS).

In phase II of the project (TF 221) Gala from orchards identified in earlier projects as producing good fruit will be used to allow direct comparison of standard CA storage Gala regimes (5% CO_2, 1% O_2 at 1.5°C) and alternative CA regimes based on lower CO_2 higher O_2 with or without SmartFresh^{TM} and the impact of dropping temperature to 0.5°C will compared with imported fruit from the Southern hemisphere in late April and June.

Materials and methods

Gala fruit was supplied from six orchards (A-F) on two picking dates 8/9th and 12/13th September 2014 chosen to correspond to 80-90% starch (pick 1) and 60-70% starch (pick 2). Fruits were harvested across a transect of each orchard ensuring representative sampling across the orchard.

On arrival at the Produce Quality Centre storage facility (Jim Mount Building) the fruit was randomised and divided among the storage treatments which are shown in Table 11. The fruit for each storage treatment was stored within a 360 L controlled atmosphere (CA) chamber containing approximately 80 kg of fruit. Each HDC treatment chamber contained one box of each of the six orchards. Each treatment chamber included samples from two picks from each of the six orchards. These twelve samples were placed as nets within the CA chambers. International Controlled Atmosphere Ltd (ICA) provided financial support for additional CA chambers, where 3 low oxygen concentrations (0.8, 0.6 and 0.4 % O_2 were trialled in conjunction with 3% CO_2 using fruit from the same orchards and pick used for HDC funded aspects of the trial. CA was established immediately or after SmartFresh™ (625 ppb 24 hours) treatment.

Additional samples of fruit were taken for internal ethylene measurement, quality assessment.

Table 11. Storage treatments.

HDC funded storage treatments, included one 15 kg box for each orchard

	Treatment	CA regime	Temp	Pick	SmartFresh
AHDB	T1	5%CO2, 1%O2	1.5°C	Pick 1	SF
AHDB	T2	5%CO2, 1%O2	1.5°C	Pick 1	
AHDB	T3	5%CO2, 1%O2	0.5°C	Pick 1	SF
AHDB	T4	5%CO2, 1%O2	0.5°C	Pick 1	
AHDB	T5	3%CO2, 2 %O2	0.5°C	Pick 1	SF
AHDB	T6	5%CO2, 0.4 %O2	0.5°C	Pick 1	
ICA	T7	3%CO2, 0.8%O2	0.5°C	Pick 1	
ICA	T8	3%CO2, 0.6 %O2	0.5°C	Pick 1	
ICA	T9	3%CO2, 0.4%O2	0.5°C	Pick 1	
AHDB	T10	5%CO2, 1%O2	0.5°C	Pick 2	SF
AHDB	T11	3%CO2, 2%O2	0.5°C	Pick 2	SF

Each treatment consisted of 1 CA cabinet in which 6 boxes, 1 box per orchard containing ~12 kg of fruit.

Assessment of fruit quality at harvest

Fruit were randomised and damaged and misshapen fruits removed. Harvest maturity measurements were conducted on two replicates of ten-fruit samples, Firmness (N) was measured on opposite sides of the fruit using Lloyd LRX texture analyser, fitted with a Magness Taylor 11 mm probe, background colour was measured using a Minolta colourmeter in lab mode, soluble solids (sugars) were measured using a refractometer and starch content was estimated using a 4% [w/v] potassium iodine and 10% [w/v] iodine solution and scored using starch clearance charts (circular-Ctifl). Internal ethylene concentration was determines according to Mousdale and Knee (1981): 0.5 mL of core cavity air-space was injected into a GC-FID (ATI-Unicam 610) fitted with a 1 m long, 6 mm OD glass packed column with 100/200 mesh alumina maintained at 130°C. Respiration rates were calculated on replicate ten-fruit samples placed in 5 L glass jars sealed for 2 hours at store temperature, CO_2 production was measured using a infra-red gas analyser (ICA Ltd). Juice samples were collected and frozen (-20°C) before analysis of acids and sugars by HPLC. Fruits were cut at the equator and the calyx end to assess for internal disorders. A second sub-set of fruit (20) was sent for mineral analysis (FAST Ltd).

Quality Assessment, Volatile collection and analysis: April/June

Fruit samples were sent to Technologists and Advisors in a number of Producer Organisations and allied industries. Gala from each orchard x storage regime combination was tasted by at least 6 people, with a total of 96 fruit being sent to each organisation for tasting by a panel of people.

Simultaneously Gala samples were assessed for fruit firmness, % Brix, juice samples were collected and frozen (-20°C) for acid analysis by HPLC and inspected for external and internal disorders.

Fruit sampling for sensory evaluation

Sensory evaluation was carried out in April and June 2015 to assess samples subjected to the full range of CA regimes. Prior to the assessments in April and June, the fruit was removed from storage and placed in shelf-life conditions at 18°C for two days before tasting. Tasting was carried out by staff belonging to seven organisations, comprising UK marketing companies, Gala growers or researchers. Thus all tasters had experience of Gala quality over several seasons. Each organisation was provided with randomly labelled fruit from all samples (96 treatment/orchard combinations). Tastings were carried out over a two day period. Thus at least eight assessments were carried out for each sample.

Protocol for sensory evaluation

Tasters were presented with whole, randomly numbered apples and asked to assess each using a 1-10 score using the following criteria.

- Aroma (1 bad - 10 excellent)
- Flavour (1 bad - 10 excellent)
- Sweetness (1 low - 10 high)
- Acidity (1 low - 10 high)
- Firmness (1 low - 10 high)
- Crispness (1 low - 10 high)
- Off Flavours (1 bad - 10 none)
- Overall Acceptability (1 bad - 10 excellent)

In addition tasters were provided with a form to include comments if they wished.

Quality analysis

Simultaneously to the sensory evaluation in April and in June 20 fruit (two 10 fruit samples) from each sample were assessed for quality as described above.

Volatile collection and Detection

Gala samples for volatile analysis were taken from store and placed in shelf-life conditions (18°C) for 48 hours. Samples of 6 fruits were cut into 4 quarters and placed inside air-tight 5L glass jars, each was sealed for 60 minutes before the contents were pumped (1 L min) across porapak columns for 30 minutes. After sampling columns were sealed and wrapped in aluminium foil, and stored at 4.5°C before analysis.

Porapak filters were desorbed using 1 ml of dichloromethane (Distol grade, ThermoFisher Scientific) 5 µg of decyl acetate was added as an internal standard. The samples were analysed using an Agilent 6890 gas chromatograph (GC) fitted with a DB-5 fused silica capillary column (30 m length, 0.25 mm diameter, 0.25 µm film thickness, (Agilent) and coupled to an Agilent 5973 mass spectrometer. Carrier gas was helium, at a constant flow rate of 1 ml/min. The column temperature was held at 60°C for 2 mins then programmed to 240°C at 6°C/min. Compounds were identified and quantified using the NIST Mass Spectral Database and by comparison to pure synthetic samples.

Statistical analysis

Interactions between orchard x picking date for HDC storage regimes and ICA regimes were analysed using Genstat 13.0.

Results

Harvest Maturity

In 2014, changes in Gala harvest maturity progressed rapidly with fruit from orchards ranging from 8.6-10.2 kg in pick one and dropping to 7.8-9.5 kg on the second pick 3 days later. Internal ethylene concentrations in fruit from orchard A, D, E and F increased rapidly between the two picks (Table 12). In general, when internal ethylene concentrations reached 100 ppb fruit are considered optimum for harvest based on data collected for Cox (Knee et al, 1985). However, Gala picked with 200-300 ppb retained ample firmness (8-9 kg) coming out of store in April even in the absence of SF. Fruit respiration by the second pick had increased significantly between the two picks (100-1000 ppb) and starch profiles of fruit at harvest ranged from 76-90% for pick 1 Gala and 85% to 63 % by pick 2; Orchard A, D, E and F starch loss increased over the 4 day period between picks in line with increased internal ethylene production. Respiration rates of Gala from the second pick increased, rising from 0.57-0.90 mL kg in pick 1 to 1.73-2.80 mL kg^{-1} h^{-1} by the second pick. Dry matter content in orchards sampled in pick 1 ranged from 12.2% to 15.6%, a similar profile of dry matter was recorded in fruit from the second pick.

Table 12. Harvest maturity measurements of 6 Gala orchards Harvested on the 8/9th and 12/13th September 2014

		Firmness	% Brix	Starch	Internal ethylene	Dry Matter	Respiration
Pick	Orchard	N		Ctifl (%)	(nl L^{-1})	%	ml-kg-h^{-1}
1	A	84.2	9.9	4.7 (75.7 %)	392.1	12.2	0.57
1	B	88.9	10.9	3.8 (74.8 %)	222.9	14.6	0.79
1	C	97.6	11.6	3.1(87.4 %)	430.3	15.6	0.84
1	D	90.2	11.0	3.6 (84.4 %)	328.0	15.0	0.90
1	E	83.1	10.9	4.3 (79.3 %)	202.3	14.0	0.79
1	F	89.1	10.6	2.6 (91.6%)	162.0	13.7	0.68
2	A	75.1	10.6	7.4 (56.6 %)	1025.7	12.7	1.73
2	B	88.6	11.2	3.5 (85 %)	101.9	14.7	1.73
2	C	91.0	12.0	3.7 (83.5 %)	398.7	16.1	2.17
2	D	86.5	11.8	4.9 (73.9 %)	637.8	15.5	2.24
2	E	81.2	11.6	5.9 (69.6 %)	574.9	14.4	2.80
2	F	84.3	10.9	4.9 (73.9%)	416.1	13.9	1.81

For the purposes of identifying the optimum CA regime required for maintaining the quality Gala in April/June data from Orchard A was excluded from the analysis, due to significant internal breakdown. Taste panel assessment averaged across 5 orchards ranged from 5.3-6.1 (Table 13). Fruit stored in 5/1 at 1.5°C or 5/1 at 0.5°C + SF produced fruit with an overall acceptability similar to imported fruit in April (6-6.1). There was no clear distinction between the optimum storage temperature and the effect of SF in the April assessment. It is important to note that CA's in this trial were generated within 24 hours of fruit reaching store temperature using nitrogen flushing and CO_2 injection, rapid establishment of CA for Gala has the potential to improve ex-store quality of the fruit in long-term storage.

Table 13. Summary of Taste panel results April 2015- data averaged across all orchards

CA regime	Temperature	SmartFresh	Overall Acceptability	Aroma	Flavour	Sweetness	Acidity	Firmness
Imported 2	n/a		6.1	5.2	5.7	5.6	3.2	6.9
5%CO2, 1%O2	1.5°C	-SF	6.1	5.3	5.6	5.4	3.9	7.1
Imported 1	n/a		6.0	5.4	5.8	5.9	3.1	7.4
5%CO2, 1%O2	0.5°C	+SF	6.0	5.0	5.5	5.6	3.6	7.4
3%CO2, 0.4%O2	0.5°C	-SF	6.0	5.4	5.4	5.4	3.5	7.5
3%CO2, 2%O2	0.5°C	+SF	5.6	5.1	5.3	5.4	3.9	7.3
3%CO2, 0.6 %O2	0.5°C	-SF	5.6	5.4	5.4	5.3	4.1	7.2
3%CO2, 2 %O2	0.5°C	+SF	5.5	5.0	5.1	5.2	3.7	7.5
3%CO2, 0.8%O2	0.5°C	-SF	5.5	5.4	5.2	5.2	4.2	7.1
5%CO2, 1%O2	1.5°C	+SF	5.4	4.7	5.0	4.8	3.7	7.2
5%CO2, 0.4 %O2	0.5°C	-SF	5.4	5.4	4.9	5.5	3.4	7.0
5%CO2, 1%O2	0.5°C	+SF	5.3	4.3	5.2	5.2	3.7	6.9
5%CO2, 1%O2	0.5°C	-SF	5.3	4.9	5.1	5.2	3.9	7.0

Comparison of firmness, % Brix acidity and flavour profiles of Gala samples in April found UK Gala was over 2 kg firmer than imported fruit at the beginning of the Southern Hemisphere season (Table 14). Southern Hemisphere fruit in April had a higher acetate ester profile providing a 'fruity' aroma to apples with approximately 10 fold higher content of 2-methylbutyl acetate, 15-20 fold higher hexyl acetate and 4 fold increase in butyl acetate. However, UK Gala were firmer and with a higher background acidity after 7 months storage and this countered the lower volatile profiles and underpins the importance of texture and acid/sugar profile when considering overall acceptability (Table 14).

A new DCA monitored regime of 3% CO_2 and 0.4% O_2 produced fruit with taste panel overall acceptability scores of 6.0 in April when averaged over 5 orchards. The quality of fruit was equal to imported Gala and Gala stored in 5/1.

When the storage behaviour of individual orchard consignments was examined under different CA regimes, Gala stored in 5% $CO_{2,}$ 1% O_2 (1.5°C) without SmartFresh^{SM} and 5% CO_2 1% O_2 (0.5°C) with SmartFresh^{SM} provided the highest number of orchard consignments where overall acceptability equalled imported fruit. Moreover, Gala from orchard C stored in 3% CO_2 and 0.8% O_2 produced the highest overall acceptable scores (6.7) of all fruit tasted. Gala from orchard C was the highest ranked orchard providing fruit with the best overall eating acceptability scores and yielded the highest number of consignments (5/15) where acceptability scores were equal or exceeded the scores (5.9-6.6) recorded for imported fruit. Gala from this orchard (Mondial) had the highest dry matter content and % Brix at harvest and was the orchard where fruit were consistently ranked with the highest concentration of volatiles.

Table 14. Individual treatment x Orchard combinations producing fruit with an overall eating quality equal to or exceeding imported Gala in April 2015

Chamber	Storage atmosphere	Temp.	SF?	Orchard	Overall acceptability	SE
AG 1	3%CO2, 2 %O2	0.5°C	+SF	D	6.3	0.7
DCA	5%CO2, 0.4 %O2	0.5°C	-SF	C	6.0	0.8
HDC 10	3%CO2, 2%O2	0.5°C	+SF	D	6.1	0.6
HDC 2	5%CO2, 1%O2	1.5°C	-SF	B	6.5	0.6
HDC 2	5%CO2, 1%O2	1.5°C	-SF	E	6.6	0.6
HDC 2	5%CO2, 1%O2	1.5°C	-SF	F	6.2	0.7
HDC 3	5%CO2, 1%O2	0.5°C	+SF	B	6.0	0.7
HDC 3	5%CO2, 1%O2	0.5°C	+SF	C	6.1	0.8
HDC 3	5%CO2, 1%O2	0.5°C	+SF	F	6.5	0.5
HDC 9	5%CO2, 1%O2	0.5°C	+SF	C	6.0	0.4
ICA 1	3%CO2, 0.8%O2	0.5°C	-SF	C	6.7	0.4
ICA 2	3%CO2, 0.6 %O2	0.5°C	-SF	C	6.3	0.7
ICA 2	3%CO2, 0.6 %O2	0.5°C	-SF	E	6.1	0.7
Imported 1					5.9	0.6
Imported 2					6.6	0.4

Overall, orchard C provided fruit with the highest firmest (92.9 N) fruit softened by only 5 N after harvest (Table 15). Orchard C (Mondial Gala) had the highest dry matter content at harvest and % Brix in fruit sampled in April (13.4%) and was equal to the consignment of imported Gala in April, however, imported Gala was 20 N softer than UK Gala stored for 7 months CA storage . Malic acid, the major contributor to fruit acidity was significantly higher in 4 out of 6 Gala orchards compared to imported Gala. Comparison of major volatile components of Gala flavour showed imported fruit to have higher acetate volatile profile, with significantly higher 2-butyl-acetate, amyl acetate, hexyl acetate compared to UK Gala in April, providing fruit with distinctive apple top-notes. Moreover, imported fruit had a higher content of the alcohol hexanol which is converted (esterified) into hexyl acetate. Despite the difference in volatile aroma profiles, the overall acceptability scores of UK fruit in some cases was similar to imported fruit based on better texture and higher ratios of acidity to sugar content. Butyrate esters were low across all orchard and imported fruit. The hexanal content of orchards B, C and E were higher than imported fruit this compound is often associated with green- unripe flavour

Table 15. The overall effect of orchard consignments on quality attributes and major volatiles of Gala (averaged across all CA regimes) April 2015

Orchard	A	B	C	D	F	G	Import 1	Import 2	**Fprob**	**$LSD_{0.05}$**
Firmness N	75.3	86.5	**92.9**	**90.1**	83.1	86.1	68.6	66.3	**<.001**	**1.37**
% Brix	10.7	12.5	**13.4**	12.7	12.3	12.2	13.5	13.2	**<.001**	**0.24**
Malic acid (µL/µL)	4.5	**6.3**	**5.2**	**6.4**	**5.7**	4.8	5.1	4.7	**<.001**	**0.30**
Acetate esters										
isobutyl acetate	1.6	2.1	2.3	3.5	2.2	2.1	1.25	1.15	**0.392**	**1.75**
Amyl acetate	0.05	0.07	0.08	**0.23**	0.05	0.06	5.93	4.30	**0.537**	**0.22**
Hexyl acetate	1.08	1.27	1.53	**2.39**	1.29	1.33	31.13	28.84	**0.627**	**1.58**
2-methyl butyrate	0.43	1.03	1.18	1.08	1.21	0.81	41.15	32.62		
2-hexenyl acetate	0.13	0.15	0.24	0.22	0.17	0.20	0.04	0.06	**0.1501**	**0.67**
Butyrate esters										
Butyl butyrate	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.01	**0.193**	**0.01**
Butyl-2-methyl Butyrate	0.03	0.04	0.03	0.04	0.04	0.03	0.01	0.02	**0.954**	**0.03**
Hexyl butyrate	0.43	0.51	0.60	0.54	0.45	0.50	1.58	1.48	**0.675**	**0.23**
Hexyl 2-methyl butyrate	0.40	0.42	0.44	0.41	0.44	0.40	2.05	1.27	**0.951**	**0.11**
Aldehyde										
Hexanal	19.3	**25.2**	**25.5**	23.0	21.7	**25.8**	16.25	13.13	**<.001**	**3.01**
2-Hexonal	4.9	**6.1**	**6.4**	5.6	5.7	**6.1**	9.84	7.79	**0.081**	**1.08**
Alcohols										
Hexanol	2.8	3.2	**3.7**	2.8	3.2	3.2	7.48	5.09	**0.09**	**0.66**
Other										
2-Hexenyl hexanoate	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	**0.81**	**0.01**
Alpha farnescene	1.64	1.67	1.82	1.57	1.74	1.76	1.86	1.35	**0.98**	**0.66**

Evaluation of CA regimes averaged across all orchards found that early harvested Gala (Pick 1) stored in 5/1 regime at 1.5°C and treated with SF provided the firmest fruit in April (Table 16), % Brix was not affected by CA regime, temperature or SF, however, Malic acid content was higher in pick 2 fruit stored in 5/1 or 3/2 and early picked fruit stored under the DCA regime (5% CO_2 and 0.4% O_2). Moreover, fruit stored in 3/2 treated with SF provided fruit with higher apple volatile esters:isobutyl, amyl and hexyl acetate. Overall, orchard effect had a bigger influence than storage regime on ex-store quality in April.

Table 16. Impact of CA regime on Gala quality (averaged across all orchards- excluding orchard A) April 2015

CA Regime ($\%CO_2/\%O_2$)	5/1	5/1	5/1	5/1	5/0.4	5/1	3/2	3/2	3/0.8	3/0.6	3/0.4		
Storage Temperature	1.5°C	1.5°C	0.5°C	0.5°C	0.5°C	0.5°C	0.5°C	0.5°C	0.5°C	0.5°C	0.5°C	Fprob	$LSD_{0.05}$
Pick (+/-SmartFresh)	1(+)	1(-)	1(+)	1(-)	1(-)	2(+)	2(+)	1(+)	1(-)	1(-)	1(-)		
Firmness N	**89.4**	86.7	86.0	83.9	86.8	83.3	85.1	86.3	85.5	83.9	85.4	**<.001**	1.851
% Brix	12.5	12.3	12.1	12.4	12.2	12.5	12.5	12.3	12.3	12.1	12.2	**0.065**	0.3253
Malic acid µL/µL	5.8	5.7	5.8	5.0	**6.5**	**6.4**	**6.6**	4.7	4.6	4.5	4.9	**<.001**	0.4075
Acetate ester													
isobutyl acetate	1.7	1.9	1.9	2.2	2.5	2.1	1.8	**4.9**	2.1	2.4	2.0	**0.364**	2.36
Amyl acetate	0.03	0.04	0.08	0.07	0.07	0.06	0.05	**0.41**	0.07	0.07	0.05	**0.377**	0.29
Hexyl acetate	1.21	1.05	1.35	1.45	1.44	1.15	1.03	**3.74**	1.35	1.34	1.18	**0.439**	2.14
2-methyl butyrate	0.83	1.03	0.93	1.07	1.05	0.96	0.77	0.63	1.07	0.94	1.22		
2-Hexenyl acetate	0.11	0.09	0.10	0.31	0.12	0.33	0.20	0.25	0.14	0.24	0.17	**0.204**	0.22
Butyl esters													
Butyl butyrate	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	**0.203**	0.01
Butyl-2-methyl butyrate	0.02	0.08	0.02	0.03	0.06	0.03	0.03	0.05	0.03	0.03	0.03	**0.299**	0.05
Hexyl butyrate	0.36	0.40	0.42	0.66	0.44	0.72	0.45	0.64	0.44	0.60	0.44	**0.223**	0.31
Hexyl 2-methyl butyrate	0.40	0.38	0.45	0.50	0.48	0.37	0.36	0.43	0.43	0.41	0.37	**0.62**	0.14
Aldehyde													
Hexanal	24.0	21.5	20.8	23.3	24.0	24.6	21.4	21.1	**26.6**	25.6	24.8	**0.067**	4.07
2-hexonal	5.9	5.1	5.0	**6.5**	6.6	5.9	4.7	5.3	**6.9**	5.5	6.4	**0.045**	1.46
Alcohol													
Hexanol	3.2	2.6	2.9	**3.7**	**3.8**	2.9	2.6	2.9	**3.7**	3.0	**3.6**	**0.038**	0.89
Other													
2-hexenyl hexanoate	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	**0.452**	0.01
Alpha farnescene	1.33	1.26	1.50	**2.52**	1.57	1.49	1.45	1.31	1.65	**2.78**	1.84	**0.015**	0.90

Second Assessment - June 2015

Taste Panel Assessment

In general, the overall acceptability scores for UK gala dropped slightly from April to June, with only one UK sample exceeding a score of 6. The highest ranking imported Gala in June produced an acceptability scores of 7.3 compared to 6.2 for SF treated. Gala stored in 3/2 (0.5°C) from Pick 1 and 2 were the most favoured UK Gala with overall acceptability scores of 6.2 and 5.8 respectively. Interestingly Gala stored in DCA regimes where oxygen was lowered to between 0.6-0.4% and 3-5% CO_2 were the next most favoured fruit. Sweetness and flavour were the two attributes that most correlated with taste panels perception of overall acceptability, while poor texture and a lack of acidity experienced with imported 2 Gala led to low overall acceptability scores (Table 17).

Table 17. Taste Panel assessment of UK stored and imported Gala: June 2015

CA/Temp/SF/Pick	Overall Acceptability	Aroma	Flavour	Sweetness	Acidity	Firmness	Crispness
Imported 1	7.3	5.6	6.1	6.0	4.0	7.0	6.8
3/2, 0.5°C, SF, P1	6.2	5.4	5.7	5.3	4.4	7.3	7.3
3/2, 0.5°C, SF, P2	5.8	4.7	5.0	5.2	4.4	7.0	7.0
5/0.4, 0.5°C, P1	5.7	5.0	5.3	4.9	4.9	7.0	7.1
3/0.6, 0.5°C, P1	5.6	4.6	5.1	4.8	4.6	6.9	6.7
3/0.4, 0.5°C, P1	5.6	5.0	5.5	5.3	4.3	6.7	6.9
5/1, 0.5°C, SF, P1	5.5	4.8	4.8	4.9	4.3	7.1	6.9
5/1, 1.5°C, SF, P1	5.5	4.5	4.9	4.9	4.4	7.0	6.8
3/0.8, 0.5°C, P1	5.4	4.9	4.9	4.8	4.2	6.9	6.7
5/1, 0.5°C, SF, P1	5.4	4.4	4.9	4.6	4.0	7.0	6.9
5/1, 0.5°C, P1	5.3	4.3	4.6	5.0	4.3	6.9	6.9
5/1, 1.5°C, P1	5.2	4.7	4.8	4.9	4.5	7.1	7.1
Imported 2	4.1	4.3	5.0	6.3	1.9	3.0	3.1

The poor firmness rating of imported 2 fruit were confirmed by penetrometer readings of 49.9 N, interestingly, the most preferred batch of imported fruit firmness measured only 58.5 N but were perceived to have ample firmness and crispness in taste panel assessment and were considered equal to UK gala where firmness ranged from 71.8-91.9 N.

Gala from orchard C maintained high % Brix in CA storage until June and exceeded values of imported fruit (Table 18). Malic acid concentrations in imported fruit were generally low while UK Gala from 3 orchards maintained significantly higher acid profile despite the length of CA storage. Imported fruit were higher in the acetate esters Isobutyl acetate and hexyl acetate, but lower in 2-methylbutyl acetate (Table 18). Moreover, imported fruit had higher undecanal which produces a citrus floral bouquet, but significantly lower content of hexanal which is responsible for green- unripe flavours.

The effect of CA regime on composition and volatile profile in fruit coming out of store in June was limited (Table 19). Pick 1 fruit stored in 5/1 at 1.5°C with SF retained the highest firmness (87.1 N), storage at 0.5°C did not improve retention of firmness or acidity. Fruit stored in 3% CO_2, 2% O_2 with SF was considered generally to have better eating quality in June despite generating fruit with firmness and volatile profiles that were indistinguishable from fruit stored under other CA regimes. In general, volatile profiles of Gala were not significantly different between CA regimes under test, with the exception of Gala stored under dynamic CA regime of 3% CO_2, 0.8% O_2 where higher concentrations of 2-methylbutyl acetate a volatile considered important in imparting 'Gala- apple flavour' was recorded (Table 19), while fruit stored in 3% CO_2, 0.6% O_2 were higher in hexanal- which imparts 'green apple flavour'

In these experiments Gala CA regimes were established using nitrogen flushing and CO_2 injection; more pronounced differences in firmness may be observed between temperature regimes where CA regimes are established through fruit respiration.

Table 18. Taste Panel assessment of UK stored and imported Gala: June 2015

Orchard	A	B	C	D	E	F	Imp 1	Imp 2	Fprob	LSD
Firmness (N)	71.8	84.6	**91.9**	**89.2**	80.7	84.1	58.5	49.9	**<.001**	1.397
% Brix	10.2	12.4	**13.5**	12.6	12.1	12.0	12.6	12.9	**<.001**	0.150
Malic acid **(µg/µL)**	5.2	**6.8**	5.6	**7.1**	**6.4**	5.4	5.3	4.4	<.001	0.282
Acetate esters(ng/g/h)-										
Isobutyl acetate	2.5	8.1	8.1	5.9	4.7	5.5	**11.8**	**14.8**	0.455	6.158
2-Methylbutyl acetate	1.70	3.70	9.10	7.20	4.00	3.00	0.02	0.01	0.289	7.000
Hexyl acetate	0.19	0.56	0.59	0.45	0.54	0.61	1.86	2.41	**0.038**	0.277
Amyl acetate	0.02	0.03	0.19	0.07	0.02	0.02	0.21	0.01	0.441	0.195
2-Hexenyl acetate	0.12	0.36	0.39	0.41	0.13	0.10	0.02	0.76	0.178	0.331
Aldehydes										
Undecanal	0.14	0.41	0.43	0.49	0.16	0.02	**41.0**	**43.3**	0.131	0.407
Hexanal	23.3	41.1	**44.4**	38.2	30.9	31.9	0.91	0.97	**0.001**	10.27
Alcohols										
Hexanol	1.93	4.07	**4.88**	3.73	3.57	3.35	2.56	3.99	**0.013**	1.551
2-Dodecanol	0.32	0.08	0.41	0.08	0.07	0.07	0.18	0.17	0.632	0.518
Ethylhexanol	0.23	0.09	0.21	0.10	0.18	0.08	0.01	0.01	0.310	0.166
Cumyl alcohol	0.12	0.09	0.24	0.12	0.10	0.09	0.04	0.31	0.419	0.164
Butyrate esters										
Butyl butyrate	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.03	0.700	0.015
Butyl 2-methylbutyrate	0.05	0.06	0.09	0.05	0.09	0.04	0.04	0.01	0.865	0.101
Hexyl butyrate	0.09	0.11	0.11	0.09	0.09	0.13	0.09	0.02	0.357	0.048
Hexyl 2-methylbutyrate	0.14	0.18	0.39	0.28	0.18	0.19	0.14	0.06	0.394	0.253
Substituted benzenes										
1,3-Diethylbenzene	0.40	0.40	4.23	0.67	0.44	0.55	0.50	0.58	0.424	4.317
1,4-Diethylbenzene	0.21	0.27	0.20	0.20	0.23	0.49	0.03	0.05	0.279	0.143
Alkanes										
Undecane	0.05	0.04	**0.08**	0.04	0.05	0.04	0.01	0.02	**0.017**	0.014
Dodecane	0.13	0.13	0.94	0.15	0.13	0.11	0.12	0.22	0.399	0.917
Tetradecane	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.03	0.425	0.008
Hexadecane	*	*	*	*	*	*	1.87	3.96	n/a	n/a
Other										
Hexyl hexanoate	0.02	0.03	0.03	0.03	0.03	0.02	0.01	0.02	0.927	0.016
à-Farnesene	1.41	1.66	1.47	1.53	1.67	2.35	0.00	0.02	0.626	1.154

Table 19. Quality assessment and volatile profile of UK Gala stored until June 2015

CA Regime (%CO_2/%O_2)	5/1	5/1	5/1	5/1	3/0.4	5/1	3/2		
Storage Temperature	1.5°C	1.5°C	0.5°C	0.5°C	0.5°C	0.5°C	0.5°C		
Pick (+/- SmartFresh)	1(+)	1(-)	1(+)	1(-)	1(-)	2(-)	2(-)	Fprob	$LSD_{0.05}$
Firmness N	**87.10**	84.96	83.55	82.25	83.51	82.41	83.14	<.001	1.891
%Brix	**12.34**	12.22	11.89	12.12	12.07	12.22	12.10	<.001	0.203
Malic acid (µg/µL)	**6.10**	5.46	4.98	5.06	**6.43**	5.71	5.56	<0.01	0.328
Acetate esters									
Isobutyl acetate	**10.21**	7.12	8.40	0.43	5.59	3.46	7.16	0.274	8.338
2-Methylbutyl acetate	2.90	4.70	2.50	3.90	4.50	3.50	2.50	0.052	9.480
Amyl acetate	0.02	0.03	0.04	0.06	0.03	0.02	0.01	0.253	0.264
Hexyl acetate	0.49	0.61	0.39	0.33	0.30	0.76	0.68	0.215	0.375
2-Hexenyl acetate	0.14	0.29	0.25	0.39	0.45	0.31	0.05	0.650	0.448
Aldehydes									
Hexanal	34.80	37.30	36.80	39.40	37.80	29.90	26.90	0.313	13.910
Undecanal	0.19	0.32	0.33	0.49	0.54	0.23	0.02	0.643	0.551
Alcohols									
Hexanol	3.80	3.43	2.46	2.40	3.41	3.65	3.76	0.106	2.100
Ethylhexanol	0.24	0.24	0.24	0.16	0.12	0.03	0.05	0.285	0.225
Cumyl alcohol	0.09	0.09	0.11	0.16	0.15	0.07	0.06	0.462	0.222
2-Dodecanol	0.27	0.02	0.02	0.13	0.20	0.11	0.04	0.680	0.701
Butyrate esters									
Butyl butyrate	0.02	0.04	0.02	0.03	0.02	0.02	0.02	0.427	0.020
Butyl 2-methylbutyrate	0.11	0.02	0.04	0.07	0.11	0.03	0.05	0.772	0.137
Hexyl butyrate	0.12	0.12	0.10	0.10	0.10	0.11	0.14	0.814	0.065
Hexyl 2-methylbutyrate	0.16	0.18	0.15	0.17	0.15	0.20	0.19	0.061	0.343
Substituted benzenes									
1,3-Diethylbenzene	0.51	0.49	0.52	0.57	0.61	0.37	0.50	0.401	5.845
1,4-Diethylbenzene	0.25	0.23	0.39	0.28	0.18	0.32	0.51	0.679	0.193
Alkanes									
Undecane	0.05	0.07	0.04	0.06	0.06	0.03	0.04	0.315	0.019
Dodecane	0.12	0.16	0.11	0.15	0.15	0.11	0.10	0.442	1.241
Tetradecane	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.513	0.011
Hexyl hexanoate	0.03	0.02	0.02	0.03	0.03	0.02	0.02	0.847	0.021

à-Farnesene	1.42	2.75	0.85	1.32	1.33	2.15	1.91	0.342	1.563

Table 19. continued Quality attributes and volatile profiles of Gala apples stored for 9 months (June) under a range of CA regimes

CA Regime (CO_2/O_2)	3/2	3/0.8	3/0.6	3/0.4		
Storage Temperature	0.5°C	0.5°C	0.5°C	0.5°C	Fprob	$LSD_{0.05}$
Pick (+/-SmartFresh™)	1(+)	1(-)	1(-)	1(-)		
Firmness N	84.06	84.80	81.69	83.50	<.001	1.891
%Brix	11.92	12.28	12.12	12.08	<.001	0.203
Malic Acid (µg/µL)	6.78	6.80	7.35	6.55	<.001	0.328
Acetate ester						
Isobutyl acetate	4.01	1.13	10.30	5.87	0.274	8.338
2-Methylbutyl acetate	1.90	**18.70**	3.50	4.00	0.052	9.480
Amyl acetate	0.02	0.38	0.02	0.02	0.253	0.264
Hexyl acetate	0.43	0.64	0.38	0.40	0.215	0.375
2-Hexenyl acetate	0.32	0.03	0.38	0.17	0.650	0.448
Aldehydes						
Hexanal	29.20	33.10	**46.10**	33.20	0.313	13.910
Undecanal	0.29	0.02	0.45	0.18	0.643	0.551
Alcohols						
Hexanol	3.19	6.06	3.95	3.38	0.106	2.100
Ethylhexanol	0.04	0.07	0.27	0.18	0.285	0.225
Cumyl alcohol	0.08	0.34	0.15	0.08	0.462	0.222
2-Dodecanol	0.02	0.01	0.37	0.71	0.680	0.701
Butyrate esters						
Butyl butyrate	0.01	0.02	0.03	0.02	0.427	0.020
Butyl 2-methylbutyrate	0.02	0.02	0.08	0.13	0.772	0.137
Hexyl butyrate	0.08	0.08	0.10	0.09	0.814	0.065
Hexyl 2-methylbutyrate	0.18	**0.73**	0.22	0.17	0.061	0.343
Substituted benzenes						
1,3-Diethylbenzene	0.42	**7.55**	0.53	0.22	0.401	5.845
1,4-Diethylbenzene	0.30	0.14	0.23	0.09	0.679	0.193
Alkanes						
Undecane	0.04	0.03	0.07	0.06	0.315	0.019
Dodecane	0.11	1.60	0.15	0.15	0.442	1.241
Tetradecane	0.02	0.02	0.01	0.03	0.513	0.011
Other						
Hexyl hexanoate	0.03	0.02	0.03	0.03	0.847	0.021
à-Farnesene	1.21	1.24	1.82	2.48	0.342	1.563

The quality and volatile profile of individual orchard consignments in each treatment that equalled or exceeded taste panel scores of 5.9 were compared with profiles of imported fruit (Table 20). No single attribute contributing to the higher overall score achieved by Imported A consignment was identified when compared with Orchard C, the highest UK ranking consignment. In many cases, Orchard C fruit were higher in 2-Methylbutyl acetate, a major component of Gala flavour compared to other consignments. Due to the nature in which consignments were selected there was a skew in the number of observations per orchard with orchard C having the greatest number of consignments making it over the threshold of taste acceptability score of 5.9.

Table 20. Quality attributes and volatile profiles of orchard consignments that equalled or exceed acceptability scores of 5.9 compared with imported fruit – June 2015

	Orchard B	Orchard C	Orchard D	Orchard E	Orchard F	Import 1	Import 2
Mean Overall Acceptability	6.0	6.4	6.2	6.2	6.2	7.1	4.1
Firmness	85.1	**92.5**	89.9	81.0	82.6	54.58	50.29
%Brix	12.3	13.5	12.2	12.1	11.8	12.40	12.55
Malic acid	**6.8**	5.6	**7.1**	**6.4**	5.4	5.3	4.4
Acetates							
Isobutyl acetate	3.79	**7.89**	**7.14**	3.49	**11.81**	**7.48**	**11.87**
Amyl acetate	0.02	**0.25**	0.03	0.01	0.02	0.01	0.03
2-Methylbutyl acetate	2.67	**11.11**	2.45	3.40	1.86	2.46	3.00
Hexyl acetate	0.73	0.49	0.33	0.66	0.21	0.42	0.43
2-Hexenyl acetate	0.07	0.42	0.80	0.22	0.02	0.40	0.38
Alcohols							
Hexanol	3.97	5.39	3.85	3.52	2.22	3.28	4.00
Aldehydes							
Hexanal	29.37	**43.13**	37.40	29.58	33.20	34.81	35.97
Undecanal	0.01	0.52	1.09	0.29	0.03	0.46	0.49
Substituted benzenes							
1,3-Diethylbenzene	0.71	**5.57**	0.35	0.25	0.44	0.47	0.51
Alkanes							
Dodecane	0.08	**1.23**	0.15	0.11	0.13	0.12	0.17
Hexadecane	1.96	**6.97**	2.80	1.99	2.24	1.90	2.94
Hexyl hexanoate	0.02	0.03	0.04	0.02	0.01	0.03	0.03
Nº of observations	3	8	2	3	1	1	1

Discussion

Results from the second year trial confirm earlier data from Phase I trials, with the influence of orchard as an important factor in the ex-store quality of Gala. Mondial Gala harvested from Orchard C generated fruit with the best eating quality with the highest firmness and high brix content coming out of store in April and June. Fruit at harvest from orchard C were high in dry matter content >15.5% and it is well established that apples with high DM content are known to have better firmness retention in store (Saei *et al,* 2011). A large proportion of the constituent dry matter is made up of sugars and starch sugars (64-80% of DM) with structural carbohydrates making up 14% (Withy, 1978) so there is a strong correlation between % Brix and DMC. There is a good correlation of high dry matter in apples at harvest and the % brix of fruit coming out of store (Palmer *et al*, 2010) allowing the opportunity for growers to predict the sweetness of fruit coming out of store.

The maturity of Gala across the six orchards varied within each pick. Orchard A ripened very rapidly between pick 1 and 2 and this rapid ripening rate led to poor storage quality, with fruit subject to significant internal breakdown. The appropriate maturity indices for Gala is not fully understood, the best performing orchard C had a relatively high internal ethylene concentration (400 ppb) at harvest at pick 1, despite retaining 87% starch. Gala from this orchard appeared to ripen more slowly compared to other fruit and the higher initial ethylene may have encouraged earlier production of volatiles. Four (2 Shinga, 2 Mondial clones) out of the remaining five orchard's produced fruit with relatively high DM >13% which is considered the threshold for maintaining quality in long-term storage (Saei *et al,* 2011), but were less preferred to orchard C Gala based on lower sweetness (% Brix). Orchard D fruit scored less favourably than Gala from Orchard C despite having similar DM content at harvest, but developed only 12.6-12.7 % brix during storage compared to 13.4-13.5% for Gala orchard C. Our perception of sweetness may be influenced by acidity and astringency. Acidity retention is an important factor in flavour perception but optimum thresholds are not well understood and the optimum ratio of sugar to acidity will have an important bearing on fruits organoleptic properties. Astringency is often associated with higher phenolic content.

Factors that affect dry matter accumulation are varied including, tree age, soil type, light interception and importantly crop load. In most cases, the orchards used in this study were well established trees, where crop load has been well managed: in orchard B Gala was cultivated on a high density spindle tree system, where better light interception overcame tree age in order produce fruit with sufficient DM. A better understanding of how to manage tree architecture in different age orchards and different planting systems and tree densities along with optimising crop load for each training system will be critical in maximising DM.

The change in firmness in Gala from harvest through to April and June assessments was minimal (4-5 N= 0.5 kg) even in non SmartFresh^{TM} treated fruit, in most cases, Gala was harvested between 75-87% starch, later picked fruit with higher degree of maturation at harvest may be more responsive to intervention with SmartFresh^{TM}.

The influence of CA regime was dependant on the time of assessment. Taste panel scores for fruit in April found fruit stored 5/1 at 1.5°C was the most preferred with those stored at 5/1 at 0.5°C + SF and DCA regime of 3% CO_2 and 0.4% O_2 (0.5°C) and imported fruit equal second. All fruit were early harvested but the effect of lowering storage temperature or the application of SF was not obvious on improving quality. There was no direct correlation between the highest scoring regimes and firmness, %Brix acidity and volatile profiles. However, fruits that scored badly in taste panels had the lowest firmness and low acidity. Earlier work by Stow and Genge (2003) found that 5% CO_2 supressed synthesis of hexyl acetate formation, an important component of apple flavour. Use of 5% CO_2 and 1% O_2 was advocated because it imparted better firmness retention during shelf-life.

By the second assessment in June overall acceptability scores were slightly lower but firmness, % Brix and malic acid content had not changed significantly. Imported fruit produced significantly higher overall acceptability scores, while UK Gala stored in 3% CO_2 and 2% O_2 (0.5°C) treated with SF had the next highest taste panel rankings. Analysis of firmness, % Brix and major volatile profiles did not correlate well with overall acceptability scores.

In conclusion, Gala with a high dry matter going into store (15.5-16% DM) yielded apples with higher %Brix coming out of store in April and June and this had a significant bearing on consumer acceptability. Some of the UK consignments were of equal eating quality to imported fruit despite imported Gala having a higher volatile profile. In many cases imported fruit were considerably softer, with less acid than UK fruit but interestingly this was not always picked up in consumer profiling. The profiles of UK Gala and imported fruit quite different and produced a different eating experience and yet in many cases these different fruit were considered equally acceptable.

The influence of CA on storage quality was dependant on time of storage and the harvest maturity. Physical attributes of firmness and % Brix were little affected by the CA regimes tested, however, taste panel scores ranked traditional 5/1 storage (1.5 or 0.5°C) as generating the best tasting fruit. Acidity, was best retained in low oxygen regimes where respiration rates are suppressed and a reduction in the amount of Malic acid respired.

When averaged across all CA treatments the profile of volatiles in each orchard were similar across all six sites, however, selection of individual orchard samples from specific CA regimes where taste panel data scores were equal to imported fruit found that orchard C apples were higher in a number of acetate ester compounds particularly 2-methylbutyl acetate.

Conclusions

- UK produced Gala stored until late April were scored equally well in taste panel assessments compared to imported Southern Hemisphere Gala.
- Orchard consignments with high % Brix (>13%) were most preferred.
- Imported fruit had a significantly higher acetate ester profile compared to UK stored fruit but often lacked firmness and acidity.
- Early harvesting and rapid establishment of CA conditions can help to maintain fruit quality into April and in some cases through to June.
- Orchards with high dry matter content (15.5-17%) generally produce fruit with better sweetness and firmness and are considered to have better eating quality and are more likely to maintain eating quality for longer.
- CA regimes 5/1 (1.5°C) without SF and 5/1 (0.5°C) with SF and the DCA regime of 3% CO_2 and 0.4% O_2 provided fruit with the best eating quality in April which was equal to imported Gala.
- 3% CO_2 and 2% O_2 + SF and the DCA regime 5% CO_2 and 0.4% O_2 DCA regime was the highest ranked CA regimes for maintaining the quality through to June.

Knowledge and Technology Transfer

EMR Association & AHDB Horticulture Tree Fruit Day 23.02.16: Improving the eating quality of UK Gala.

New Protocols to keep Gala in good shape. AHDB-Grower March 2016.

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