Apple eating quality research for improved value chain delivery

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Media Summary

Eating quality is a key driver of consumer demand for apples and all sectors of the apple industry agree that consumption could increase if eating quality was improved. This project investigated the effect of post harvest supply chain factors on eating quality of apples. Project partners were the pack house Batlow Fruit Co-operative and the retailer Coles.

Eating quality of three Australian apple cultivars, which were Fuji, Pink Lady and Red Delicious, was investigated in relation to three factors in a controlled study:

1) **Storage time after harvest;** fruit were evaluated at four time points (June, August, November and January). Apple evaluated at the first time point had been recently harvested and air stored. Apples evaluated at subsequent time points were stored in CA atmosphere and were 1-MCP treated.
2) **Cooling method**; at each time point following washing, sorting, grading and packing, static cooling, which was current best practice, was compared to rapid cooling to bring apples more quickly to optimum temperature for distribution.
3) **Storage temperature**; apples were subjected to 10 days of storage at either ambient or chilled temperatures.

A trained sensory panel measured the sensory properties of apples in terms of appearance, odour, taste, flavor, texture and mouthfeel. Fruit firmness and total soluble sugar content were measured instrumentally in parallel, and visual assessments were conducted on intact and cut apples.

Visual quality of all apples was good. Each cultivar had distinct sensory properties which displayed variations throughout the year. Rapid cooling provided somewhat better texture and mouthfeel for the air stored apples evaluated at the first time point but had no impact on apples stored in controlled atmosphere and treated with 1-MCP during the remainder of the season.

Loss of eating quality due to ambient storage temperature, when compared to chilled storage, was largest for the recently harvested air stored apples and was less pronounced for apples that were stored in controlled atmosphere. Air stored Red Delicious did not maintain its textural eating quality well (in particular when statically cooled and subsequently stored at ambient temperatures) and to a lesser extent this was the case for Fuji (when stored ambient). Otherwise, sensory and instrumental quality of apples in the controlled study was mostly maintained well throughout the year. The exception was Red Delicious, at time point 4, in January which was somewhat *floury*.

Fruit sourced at point of sale from three supermarkets differing in apple turnover rate was also evaluated. Apples from a high turnover store were of the highest sensory quality, but some apples from the medium turn store were lower in eating quality than apples from the low turnover store. In some cases eating quality of apples at retail was poorer than apples in the controlled part of the study, which were kept at ambient temperatures for 10 days, suggesting factors other than storage temperature should be considered to explain losses in eating quality.

In general, consumer preferences for apples are determined by a combination of taste and texture characteristics. Consumer research fell outside the scope of this study and it is not known when fruit of lower eating quality becomes unacceptable to consumers, thereby influencing repeat purchase.

Eating quality of air stored Red Delicious, subsequently stored at ambient temperatures, could be improved by the rapid cooling technology. The lower eating quality of fruit in some supermarkets seems at least in part not related to the factors tested in this study.

It is recommended that the apple industry and their supply chain partners further investigate potential causes for poor eating quality encountered in supermarkets, taking several aspects of the supply chain into account, and to investigate whether it is worthwhile to add sensory assessments to routine quality assurance procedures to predict eating quality. It is also recommended that consumer research is carried out to determine at what point eating quality becomes unacceptable for key sensory properties of apples.

Technical Summary

Eating quality is a key driver of consumer demand for apples amongst Australian consumers. The Apple and Pear Supply Chain Efficiency review found all sectors of the apple industry to agree that consumption could be increased if the eating quality delivered to consumers was improved (Ridge Partners, 2005). The current project was commissioned by HAL and APAL to investigate if and how eating quality could be improved by post harvest supply chain factors. Project partners were the pack house Batlow Fruit Co-operative and the retailer Coles.

Sensory and instrumental quality of three Australian apple (*Malus domestica*) cultivars, which were Fuji, Pink Lady and Red Delicious, was investigated in relation to three post-harvest supply chain factors; 1) storage time after harvest, 2) cooling method, and 3) storage temperature. At the first time point (June), apples had been recently harvested, and were assessed following air storage. At time points two to four (August, November and January), apples were removed from the Batlow Co-operative cool rooms, where they had been stored under controlled atmosphere (CA) following treatment with 1–MCP.

Apples were either statically cooled according to current best practice, or rapidly cooled, in order to reduce the time taken to reach the optimum storage temperature following washing, sorting, grading and packing. Apples were sent via a Coles Distribution Centre and Coles store to CSIRO, where they were stored at either ambient (~20°C) or chilled (5°C) temperatures for 10 days, thus providing four variations of cooling method and storage temperature for each of the three cultivars. A trained descriptive sensory panel measured the sensory properties of the apples using a sensory vocabulary of 19 attributes (covering appearance, odour, taste, flavour, texture and mouthfeel) and a standardized method of assessment. Visual quality assessments and instrumental measurements (FFP, Brix %) were collected in parallel.

Fruit sourced at point of sale from the supermarket was also evaluated. Fruit was sourced from three stores differing in their apple turnover rate.

Visual quality of apples was good throughout the study. Each apple cultivar had a distinct sensory profile. There was variation in sensory and instrumental quality within cultivars throughout the year. Following commercial practices, apples for this study derived from different growers at each of the time points.

The largest differences as a result of storage temperature and cooling method were found at time point 1 (June) where fruit had been air stored. Storage temperature for 10 days had a large impact on sensory and instrumental quality at this time point, with chilled storage better retaining quality than ambient storage. Red Delicious showed larger changes in quality than the other two cultivars. Cooling method had a small, but significant, effect on the texture of apples. Rapidly cooled apples were slightly more *crispy, juicy, crunchy, firm* and less *floury* than statically cooled apples. The effect was most pronounced for Red Delicious apples that had been stored at ambient temperatures.

At subsequent time points (Aug, Nov and Jan), where apples had been CA stored and 1-MCP treated, the effect of subsequent storage temperatures was less pronounced, and cooling method had no effect on sensory and instrumental quality of apples.

Air stored Red Delicious did not maintain its textural eating quality well (in particular when statically cooled and subsequently stored at ambient temperatures) and to a lesser extent this was the case for Fuji (when stored ambient). Otherwise, sensory and instrumental quality of apples in the controlled study was mostly maintained well throughout the year. The exception was Red Delicious, at time point 4, in January which was somewhat *floury*.

Apples from supermarket stores displayed more variation in sensory quality than apples submitted to the four controlled cooling method x storage temperature conditions. Eating quality of apples from the commercial supply was in some cases poorer than eating quality of apples kept at ambient temperatures for 10 days. Apples tended to be more *floury*.

Apples sourced from the high turnover store were of the highest sensory quality, compared to both medium and low turnover stores. Some apples from the medium turn store were lower in eating quality than apples from the low turnover store.

In general, consumer preferences for apples are determined by a combination of taste and texture characteristics. Consumer research fell outside the scope of the current study and it is not known when fruit of lower eating quality becomes unacceptable to consumers and may reduce likelihood of repeat purchase.

The rapid cooling method provided somewhat better sensory quality for air stored apples from the first time point immediately following harvesting but had no impact on apples stored in CA and treated with 1-MCP during the remainder of the season. In particular air stored Red Delicious apples subsequently stored at ambient temperatures in the supply chain would benefit from rapid cooling technology.

It is recommended that the apple industry and their supply chain partners further investigate what sensory attributes, and at what levels, determine the eating quality of apples for consumers, in particular regarding their willingness to accept.

It is also recommended to further investigate to what extent poorer eating quality is observed in supermarkets and better determine how potential losses in eating quality may occur. Such losses may be due to apples being marginal regarding quality specifications at the pack house or upon arrival in the distribution centre, more rapid decrease in eating quality due to other storage or handling practices, or due to environmental and other factors in the supermarket that were not considered in this project (such as airflow and exposure to lighting).

Although fruit had good visual quality, physical and chemical measurements before storage could not fully predict firmness and sensory properties at the time of consumption. It is recommended that the apple industry would investigate whether sensory assessments should be used during the supply chain to better predict sensory quality at point of sale. If this were the case, it may be worthwhile to consider adding sensory assessments to routine quality assurance procedures, for example at the retail Distribution Centre.

CONTENTS

1. INTRODUCTION

A review of the Apple and Pear Supply Chain Efficiency found eating quality to be a key driver of consumer demand for apples amongst Australian consumers (Ridge Partners, 2005). All sectors of the industry agreed that consumption could be increased if the eating quality delivered to consumers was improved[1].

Consumers seek products with optimal, but also consistent, eating quality. Product variability of horticultural produce is larger than processed foods. Moreover, apples are not harvested all year round, and the requirement to store apples for long periods may add to the variability in eating quality.

Many factors have been found to influence eating quality (Little & Holmes, 2000; Wills, McGlasson, Graham & Joyce, 1998). Pre-harvest factors include initial selection of cultivar, rootstock, location, production practices, seasonal and climate variations and maturity at harvest. Post-harvest factors that influence apple quality in the supply chain (from pack house to consumer) include atmosphere (CO_2:O_2 ratios, relative humidity (RH)), handling practices, temperature and duration of storage at the pack house, distribution centre (DC), retail store and by the consumer (as the consumer keeps the apple from the point of purchase). A summary of factors is shown in Table 1.

Table 1: Factors affecting eating quality of apples, including both pre-harvest (grey; outside the scope of this project) and post-harvest factors (in black text).

During production	During harvest	During storage	During distribution	During retail
Cultivar	Fungicide	Atmosphere	Handling sorting/grading	Temperature
Region	MCP	Temperature	Packaging/Palletizing	Humidity
Climate	DCP	Duration	Transport	Duration
Season	Calcium	Humidity	Duration	Handling
Maturity	Sorting	Ethylene	Temperature variations	
Tree culture	Cooling delay		Humidity/condensation	

Duration of storage is widely accepted to be a key factor of eating quality (Little & Holmes, 2000). Extensive research has been conducted in the apple industry over the last 50 years into optimizing storage of apples to extend their storability. Substantial increases in storability have been made by the introduction of controlled atmosphere storage with the use of this technique now standard across the apple industry. SmartFresh (1-MCP), which inhibits the reaction of ethylene and therefore extends the shelf life, has received considerable research attention and is becoming increasingly common in the apple industry. Based on the expected duration of storage, different storage conditions are usually adopted, with controlled atmosphere storage replacing air stored apples around May (Ridge Partners, 2005).[1]

[1] Most apples are harvested between February and May in Australia, with harvest times depending on cultivar, region and season

Temperature in post-harvest supply chains can impact the quality of the apples through several mechanisms. Most importantly, respiration increases with temperature, thus the colder the temperature of the apples the slower the respiration and the longer the storage life. Delays in reducing the temperature and the time taken to reach temperatures that reduce respiration significantly may affect eating quality. Fluctuations in temperature, even by a few degrees, may also impact eating quality. In addition, condensation may occur from temperature fluctuations, which may result in loss of packaging structural integrity due to moisture. This in turn can result in compression bruising of the fruit. Once apples leave the pack house and enter the rest of the supply chain, they may be exposed to various temperatures for various lengths of time, e.g. depending on conditions during distribution, in the supermarket and/or at the home of the consumer.

The effect of temperature on apple quality has been the subject of research, although few studies have included formal sensory evaluations by a trained panel. A loss of instrumentally measured firmness was generally found with higher temperatures and longer storage times (Little & Holmes, 2000; Wills et al, 1998). Storage conditions were found to affect the degree of loss in firmness (Little & Holmes, 2000; Konpacka & Plocharski, 2004). A distinct effect of storage condition (in packhouse and during subsequent storage) on the relation between firmness and acceptability of fruit texture was reported in one study (Konpacka & Plocharski, 2004). To our knowledge, no studies have been published that investigate the effect of rapid cooling technology (to more quickly decrease fruit temperatures once they are washed and graded) on sensory properties of apples.

Quality of apples is assessed within the Apple Industry using visual standards and some physical and chemical measurements. Product description languages, that detail appearance specifications, have been written for the most widely grown apple cultivars in Australia (APAL, 2008). The most common physical and chemical measurements used to assess quality in the apple industry are firmness, usually measured with a penetrometer as FFP, starch score which is based on the percentage of the core and cortex areas stained dark blue when dipped in iodine and then compared to a grading chart, and finally the total soluble solids content which is known as Brix %. These quality measurements are usually conducted at the time of harvest but can be conducted at various points along the supply chain.

Variations in supply chain factors, beyond the optimal or anticipated in the supply chain, can result in unanticipated quality of apples even when the initial quality measurements made at harvest were as specified. This in turn can result in apples been rejected by retailers if they perform subsequent measurements when initially received.

Retail distributers often have their own quality specifications. Coles uses visual specifications related to size, shape, colour as well as absence / tolerance of defects (Appendix A). Coles also provides minimum firmness and Brix % levels. Key sensory attributes are described, but not quantified. Specifications for premium and standard quality differ in requirement for certain visual characteristics (size, colour) and tolerance levels of minor and major defects. Quality specifications of Woolworths are similar (Woolworths, 2010).

Visual quality of apples is checked by Coles in the DC, whereas instrumental measurements are not carried out systematically on all batches. There is relatively more emphasis on conducting Brix % measurements at the start of the apple season and firmness measurements towards the end of the season.

A review of the Apple and Pear Supply Chain Efficiency showed that problems with eating quality often occur during the transition from air stored fruit to controlled atmosphere fruit in May, and as the controlled atmosphere fruit finishes in November-December (Ridge Partners, 2005). In addition, storage of apples in the supermarket was also found to be a potential contributor to losses in eating quality (Ridge Partners, 2005). An Australian consumer survey found that the key negative comments about eating quality of apples related to taste (sour, lack of flavour) and texture (floury, not crunchy, poor texture in general), but that apples generally had an appealing appearance (McKinna, 2004). Disappointing quality may lead consumers to turn to competing products, such as other fruits, but also nutritional snacks and shelf-stable fruit packs (Ridge Partners, 2005).

Most research on consumer preferences for apples in relation to sensory properties found that preferences were determined by a combination of appearance, taste and texture characteristics (Daillant-Spinnler, MacFie, Beyts & Hedderley,1996; Faber, Mojet & Poelman, 2003; Harker, Gunson & Jaeger, 2003; ; Jaeger, Andani, Wakeling & MacFie, 1998; Péneau, Hoehn, Roth, Escher and Nuessli, 2006). Little research has been conducted on preferences of Australian consumers.

Acceptance of 120 UK consumers for 12 cultivars of apples from the Southern Hemisphere (Splendour, Golden Delicious, Granny Smith, Top Red, Celeste and Compact Golden Delicious from South Africa; Royal Gala, Fuji, Braeburn, Aurora, GS330 and Fiesta from New Zealand) were investigated in relation to sensory properties of the apples (Daillant-Spinnler et al, 1996). Acceptance was found to be highly determined by texture and flavour attributes. Two groups of consumers were identified; one group preferred a sweet, hard apple and the other a juicy, acidic apple.

Another study investigated consumer preferences for fresh and aged apples, using three cultivars (Belle de Boskoop, Cox's Pippin Orange and Jonagold) at three levels of mealiness each (Jaeger et al, 1998). The study was conducted in Denmark and the United Kingdom. By relating consumer preference to trained sensory panel data, consumer preferences of one segment were found to be driven by hard, crisp and juicy texture and by grassy odour. Preferences of a second consumer segment were driven by the fruity/flavour attributes Cox-like, plum/cherry, pear-like and sweet. Mealiness was considered a negative quality attribute, which was also associated with fluffy appearance, stale flavour and floury and granular texture.

Several studies have related consumer acceptance to instrumental measurements, and have found consumer acceptance to increase with Fruit Firmness Pressure (Harker et al, 1998; Wills, Bambridge & Scott, 1980). Harker et al (1998) studied acceptance by US consumers for Red Delicious, Gala, Fuji, Golden Delicious and Braeburn apples using separate trials for each cultivar. Non-destructive and destructive measurements were conducted including firmness, Brix %, titratable acidity (TA) and pH. Firmness was the primary edible quality factor that contributed to consumer acceptance and preference. High Brix % and/or TA contributed to further improvements in consumer acceptance, but usually only in apples that were firm.

An Australian study investigated the effect of storage on perceived quality of Red Delicious (Wills et al, 1980). Apples were air stored at four storage temperatures from 0 to 20°C for up to 140 days. At regular intervals, overall quality as well as texture, and flavour quality were assessed by an informal taste panel. In addition, FFP, TA, SSC and starch were measured. Flavour, texture and overall quality declined with time in storage. High temperature fruit declined at faster rates than that of fruit held at lower temperature. There was a strong correlation between FFP and overall quality.

The above studies indicated that texture and flavour attributes played an important role for consumer acceptance. Flouriness / mealiness had a negative impact on consumer acceptance of apples, and crispiness, juiciness and hardness/firmness had a positive impact on acceptance. Sweet and acid taste, as well as specific flavour attributes, were also important attributes for consumer liking, but consumers differed more in their liking for them (Daillant-Spinnler et al, 1996, Jaeger et al, 1998 and also Faber et al, 2003; Poelman, 2008; Thybo, Kuhn & Martens, 2003). Thus, for consumers that like relatively sweet apples like Fuji, the more sweet the apple the more they might like it, whereas for consumers preferring Pink Lady apples the balance of sweetness and acidity may be more important.

In studies involving multiple countries, little evidence of cross-cultural differences was found (Jaeger et al, 1998), and therefore it seems reasonable to assume that consumer preferences and key sensory attributes are also relevant in the Australian context.

This project was initiated to determine the effect of critical factors in the post harvest supply chain on sensory and instrumental quality of apples. The project examined an Australian apple supply chain over one year of storage conditions. Project partners were the pack house Batlow Fruit Co-operative and the retailer Coles. In addition to storage time after harvest, and in collaboration with project partners and other stakeholders, cooling method (rapid versus static cooling after removal from storage at the pack house) and storage temperature (storage over 10 days in respectively chilled and ambient temperatures) were selected as design factors. Further details are provided in the Materials & Methods.

This research aimed to provide insights that can help improve overall consumer satisfaction with eating quality of apples, and thereby help ensure a viable future for apple growers. The findings will enable the Australian apple industry to determine with greater accuracy how to retain or improve sensory quality of apples throughout the supply chain.

The specific objectives of the current study were:

- To identify the key sensory properties that consumers use to evaluate the quality of apples
- To measure the effect of critical supply chain ‘quality impact’ factors on the sensory and instrumental quality of three Australian apple cultivars in a controlled way. Supply chain factors tested will be; storage duration, cooling method and storage temperature
- To measure the sensory and instrumental quality of three Australian apple cultivars deriving from retail stores that vary in apples sales turn-over
- To communicate the impact of supply chain ‘quality impact’ factors on the sensory quality of apples to supply chain partners in a report and provide them with recommendations to retain or improve sensory quality of apples.

2. MATERIALS AND METHODS

2.1 Overview

The project focused on the sensory and instrumental quality of three Australian apple cultivars (*Malus domestica*) as a function of selected supply chain factors. The apple cultivars were chosen in consultation with the APAL Business Manager Tony Russell and Horticulture Australia Limited (HAL) and included:

1. Fuji
2. Pink Lady
3. Red Delicious

These apple cultivars were chosen for several reasons. Together they represented a large proportion of apples sold. These apples were also different in their sensory characteristics and were deemed to be representative of a wide range of apples consumed by Australian consumers. All three cultivars were harvested around the same time and available most of the year, which had practical advantages for the design of the study.

Experimental data was collected in two main tasks:

- Sensory and instrumental quality of apples as a function of the supply chain factors storage duration after harvest, cooling method and storage temperature *(conditioned trial).*
- Sensory and instrumental quality of apples from fruit sourced in supermarkets that vary in apple sales turnover, to provide a benchmark

The benchmark study was carried out to compare eating quality of apples available in stores with the results of the conditioned trial. Further details about both tasks are provided in the sections below. Background information was gathered through literature search and discussions with stakeholders.

Project partners in this project were the pack house Batlow Fruit Co-operative and the retailer Coles. Contributions of both partners to this project were:

Batlow Fruit Co-operative:

1. Contributed to determining the objectives and experimental design of the study.
2. Provided three cultivars of apples (Pink Lady, Fuji and Red Delicious, ~2400 fruit from each cultivar at each time point)
3. Provided storage for all apples and allowed for apples of each cultivar to be removed from storage at four time points throughout the year.
4. Washed/sorted/treated/graded and packed all apples to retail standards.
5. Provided pilot rapid cooling equipment and submitted half of the apples to this cooling method
6. Placed temperature monitors in apples boxes at time of packing (data loggers and instructions were provided by CSIRO)

7. Sent apples from each cultivar at each time point to the Coles Eastern Creek DC.
8. Provided relevant details of postharvest handling and treatments
9. Provided information about supply chain processes and apple specifications

Coles:

1. Received one shrink wrapped pallet (containing 36 boxes) at the Coles Eastern Creek DC from Batlow four times throughout the year and sent this pallet to the Coles Lindfield store in NSW
2. Provided visitor access to a CSIRO researcher to Coles store in Lindfield to pick up these pallets of apples.
3. Nominated 3 stores for the benchmark study
4. Provided information about supply chain handling processes
5. Provided a copy of their apple quality specifications

2.2 Sensory and instrumental quality as a function of selected supply chain factors

2.2.1 Experimental design - critical supply chain factors

Based on information from the literature, discussion with the project partners as well as other stakeholders (including HAL and APAL) the factors storage duration, cooling method and storage temperature were chosen as design factors for this project.

In summary, sensory and instrumental quality of three apple cultivars (Fuji, Pink Lady and Red Delicious) was studied as a function of the following:

1. Duration of storage - four different assessment periods throughout the year were taken into consideration, starting with relatively freshly harvested apples, until they had been stored for over nine months. The time points that apples were assessed were June ‘09, Aug ‘09, Nov ‘09 and Jan ‘10. Based on the standard operating procedures of Batlow, apples were air stored at the first time point, and CA stored / 1-MCP treated at the latter three time points.

2. Cooling method and storage temperature - at each assessment period, apples of each of the three cultivars were submitted to variable time / temperature conditions:

a. Static cooling, followed by ambient storage (~20ºC) for 10 days
b. Static cooling, followed by chilled storage (5ºC) for 10 days
c. Rapid (forced air) cooling, followed by ambient storage (~20ºC) for 10 days
d. Rapid (forced air) cooling, followed by chilled storage (5ºC) for 10 days

Rapid cooling was compared to static cooling to determine whether rapid cooling retained apple quality better. Static cooling is the current practice at Batlow Fruit Co-operative, which involves removing apples from CA or cold storage and then sorting, washing, grading, packing and palletising followed by storage at 2°C for an unspecified number of hours until transporting.

Rapid (forced air) cooling, on the other hand, uses cold air to quickly decrease apple temperature once they’ve been sorted, washed, graded, packed and palletised. As far as the authors are aware, rapid cooling is not currently applied in the Australian Apple Industry.

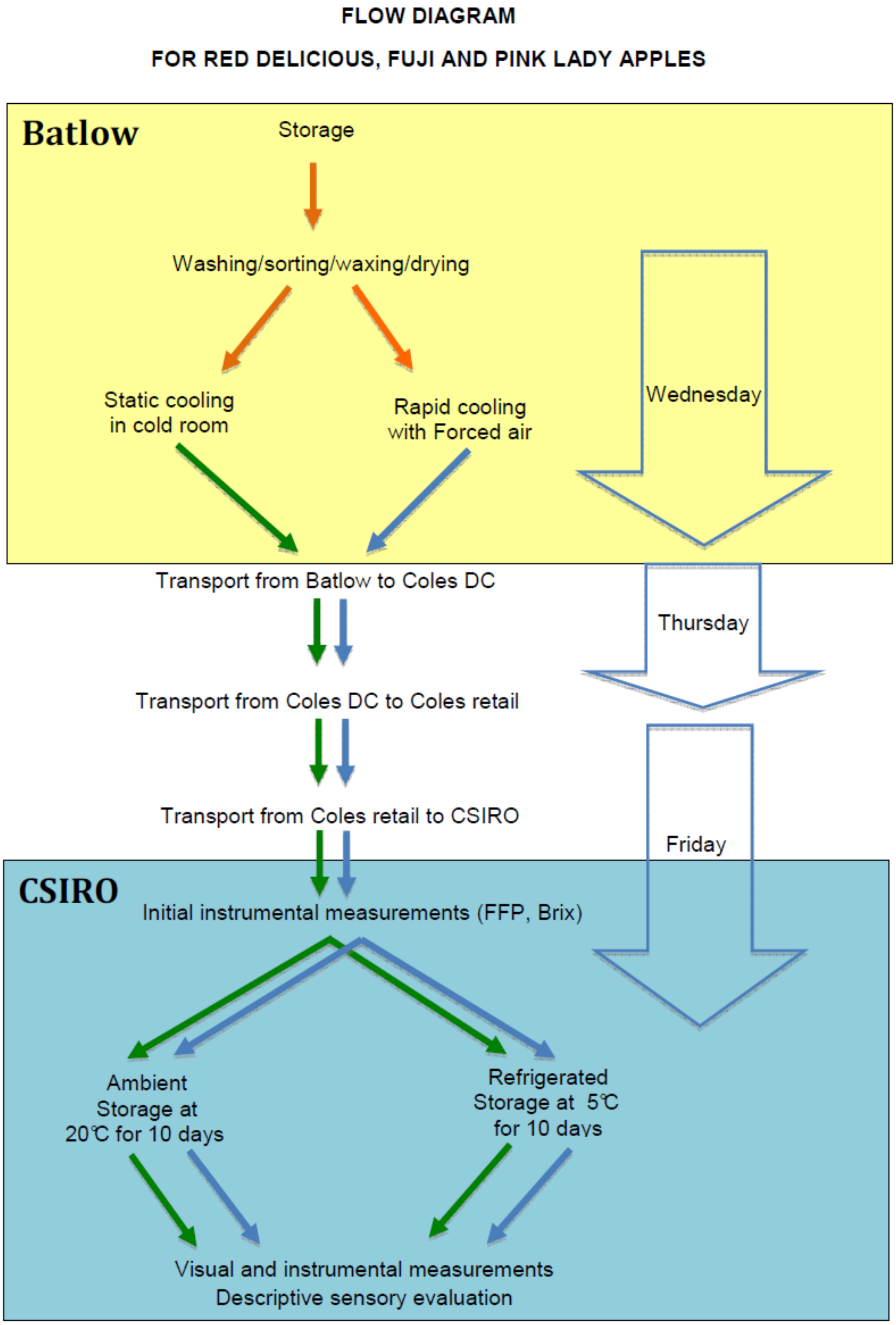
Chilled and ambient storage after removal from CA or cold storage were selected to represent average lower and upper temperatures that fruit may experience once it leaves the cold rooms of the pack house. Ten days of storage was selected as this represented a reasonable period of time, up to which fruit may be expected to experience in latter parts of the supply chain (in supermarket and at consumer's residence)[2]. The systematic design combining cooling method and storage temperature enabled an investigation of the effectiveness of rapid and static cooling technology in relation to subsequent storage temperature conditions.

Figure 1 provides a schematic overview of the experimental design. Batlow Fruit Co-operative provided the necessary pilot scale equipment for this study. The cooling (rapid versus static cooling) occurred at Batlow Fruit Co-operative. Apples then were sent to the Coles Distribution Centre, before transfer to a Coles supermarket. Apples were collected from the supermarket by CSIRO. Subsequent storage at chilled versus ambient conditions took place at the CSIRO facilities in North Ryde.

[2] Sensory and instrumental evaluations were carried out on three consecutive days (see also Table 1). The storage time is therefore 10 days on average. For purpose of clarity this will further be called 10 days.

Figure 1: Overview experimental design for supply chain study.

Evaluations conducted at four time points (June '09, Aug '09, Nov '09 and Jan '10).



2.2.2 Samples

At each of the four time points during the year, apples were submitted to the supply chain processes and the four cooling method / temperature conditions described in Figure 1.

Samples at each time point derived from different growers (see Table 2). Apples at the June evaluation (time point 1) were air stored, whereas apples from the other time points were CA stored and 1-MCP treated. Table 3 describes the samples and the codes used for these samples throughout the report.

Table 2: Storage conditions and growers* at each of the four assessment time points

	Storage condition	**Red Fuji** Grower	**Pink Lady** Grower	**Red Delicious** Grower
Time point 1	Air stored	GF	GA	GB
Time point 2	CA + 1-MCP	GF& GH	GE	GD
Time point 3	CA + 1-MCP	GF	GA	GG
Time point 4	CA + 1-MCP	GG	GC	GI

* Grower information is coded for confidentiality purposes

Table 3: Description of the samples

Sample code	**Cultivar**	**Cooling method**	**Storage temperature**	**Assessed at time point**
FJ Rapid 5	Red Fuji	Rapid	5°C	1, 2, 3, 4
FJ Static 5	Red Fuji	Static	5°C	1, 2, 3, 4
FJ Rapid 20	Red Fuji	Rapid	20°C	1, 2, 3, 4
FJ Static 20	Red Fuji	Static	20°C	1, 2, 3, 4
PL Rapid 5	Pink Lady	Rapid	5°C	1, 2, 3, 4
PL Static 5	Pink Lady	Static	5°C	1, 2, 3, 4
PL Rapid 20	Pink Lady	Rapid	20°C	1, 2, 3, 4
PL Static 20	Pink Lady	Static	20°C	1, 2, 3, 4
RD Rapid 5	Red Delicious	Rapid	5°C	1, 2, 3, 4
RD Static 5	Red Delicious	Static	5°C	1, 2, 3, 4
RD Rapid 20	Red Delicious	Rapid	20°C	1, 2, 3, 4
RD Static 20	Red Delicious	Static	20°C	1, 2, 3, 4

Temperature logging devices were placed in the core area of apples at the pack house to provide data on flesh temperature during rapid cooling compared to static cooling, and also to provide information on any temperature abuse during transport of the apples.

2.2.3 Sensory descriptive analysis

In order to determine the sensory differences between the samples (within and between apple cultivars), CSIRO’s sensory panel carried out descriptive sensory analysis of the twelve samples at each of the four time points.

Descriptive sensory analysis was conducted in the sensory laboratory of CSIRO Food and Nutritional Sciences (CFNS), which meets International Standards on Sensory Analysis (ISO 1988).

The descriptive sensory panel consisted of ten assessors (all female, age 44.5 ± 7.2 years) that had previously been screened for a good sense of taste and smell (ISO 8586-1:1993) and had extensive experience in descriptive analysis. The panel consisted of the same panellists throughout all evaluations where possible, so that results between time points were directly comparable.

Seven two-hour training sessions were held to develop and define a sensory vocabulary and a standardised method of assessment, to familiarise the panellists with the samples and to obtain panel agreement. The consensus descriptive vocabulary consisted of 23 attributes, in terms of appearance, odour, flavour and texture / mouthfeel (Table 4). At subsequent time points (2, 3 and 4) the same sensory vocabulary and method of assessment were used. Before evaluations at each of these time points the panellists took part in two further two-hour training sessions. Fruit were removed from conditioning the evening before the evaluation, so that all fruit were evaluated at room temperature. The panellists received one half of an apple which had been cut longitudinally and was assessed immediately after cutting.

The trained panel quantitatively evaluated the sensory properties of the apple samples at each time point in triplicate using the consensus vocabulary and the consensus method of assessment. At each time point, the sensory evaluation occurred on three consecutive days. Each day, the panellists evaluated all twelve samples. Apples from the same cultivar were evaluated as a block, and the order of blocks was balanced over the three days of evaluation. Plain water and crackers were provided as palate cleansers. To reduce panellist fatigue, a one minute inter-stimulus interval was imposed between samples and a 10 minute break was imposed after every four samples. All evaluations were carried out in individual sensory booths under white light.

The samples were blind-coded with random 3-digit codes and the order of sample assessment was randomised across panellists to account for first order and carryover effects. The experimental design was produced using the design generation package – CycDesigN (Whitaker, D. Williams, E.R. and John, J.A. (2002) CycDesigN Version 2: A package for the computer generation of Experimental Designs. CSIRO, Canberra, Australia). Attributes were rated on 100mm unstructured line scales anchored at 5 and 95%, respectively, with extremes for each descriptive term. Data were recorded and stored using the Compusense sensory data acquisition software (version 4.6, 2004; Compusense Inc., Guelph, Ontario, Canada).

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Table 4: Defined sensory vocabulary for descriptive evaluation of apples

Attribute	**Definition**	**Related terms**
Appearance		
Cream colour	The cream colour of the cut surface i.e. inside the apple. Ranging from 'low' to 'high'	
Green colour	The green colour of the cut surface i.e. inside the apple. Ranging from 'low' to 'high'	
Odour		
Overall impact	The intensity of the overall aroma of the sample. Ranging from 'low' to 'high'	
Green	The aroma associated with tree leaves / branches. Ranging from 'low' to 'high'	Grassy, leaves
Pear	The sweet aroma associated with honey/ripe pear. Ranging from 'low' to 'high'	Sweet, honey, ripe pear
Floral	The sweet fragrant aroma associated with flowers. Ranging from 'low' to 'high'	Perfume, scented, bouquet
Earthy	The earthy aroma associated with soil. Ranging from 'low' to 'high'	Musty, damp, dirt
Texture		
Whole Apple		
Crispiness	Amount of sound generated and force required when the sample is first bitten with the front teeth	
Juiciness	Amount of juice released from the sample in the first three chews, when chewing with the molars	
Crunchiness	Amount of noise generated when chewing with the molars	
Floury	Degree to which the flesh breaks down in the mouth during chewing	Fibrous, mealiness, powdery
Firmness	Force required to chew with the molars. Ranging from 'soft' to 'hard'	
Skin toughness	Toughness of the skin, primarily assessed by the amount of skin remaining after the flesh being swallowed. Ranging from 'low' to 'high'	
Flavour/Taste		
Overall flavour impact	The intensity of the overall flavour of the sample.	
Green	The flavour associated with tree leaves / branches	Grassy, leaves
Pear	The sweetness associated with honey/ripe pear	Sweet, honey, ripe pear
Earthy	The earthy aroma associated with soil	Musty, damp, dirt
Sweet	The intensity of sweet taste	
Bitter	The intensity of bitter taste	
Acidic	The intensity of acid taste	Tangy, tart like, citrus, vinegar
Aftertaste/Afterfeel		
Sweet	The residual intensity of sweet taste after swallowing the sample	
Acidic	The residual intensity of acid taste after swallowing the sample	Tangy, tart like, citrus, vinegar
Astringency	The dry puckering afterfeel left in the mouth after swallowing	Chalky

2.2.4 Instrumental measurements

Upon arrival of the fruit at CSIRO, and before submitting the apples to ambient or chilled storage, a representative sample of 30 fruit was taken from each cultivar in each cooling method condition. Two instrumental measurements were conducted. The texture of the apples was measured as Fruit Firmness Pressure (FFP), and was determined with a HortPlus electronic penetrometer. Dual penetrometer readings were made on the equatorial region at positions perpendicular to each other. The total soluble solids (TSS) was recorded for each apple as Brix % using a digital refractometer (Pal Atago).
After 10 days of conditioning and prior to the start of the sensory evaluations, a sample of 100 apples was visually inspected for any quality defects. This quality assessment recorded the occurrence of shrivel, scald, decay and bruising on the intact apple and also the occurrence of internal browning, decay and bruising when the apple was cut open prior to consumption. Incidence of quality defects was recorded and only apples with acceptable quality for human consumption were used in the sensory evaluation.
The collection of instrumental data was done in parallel with sensory evaluation on the same apples. One half of the apple (the intact half) was used for sensory evaluation, whereas the other half was used for the instrumental measurements. The FFP and Brix % were measured as described above.

2.3 Sensory and instrumental data from fruit sourced in supermarkets

This benchmark study was carried out in parallel with time point 3 (Nov '09), as it was expected that differences in eating quality may become more pronounced over time.

2.3.1 Samples

Coles selected three supermarkets that represented different conditions that may affect quality of apples. A representative from the Coles Distribution Centre (DC) nominated three stores within their district on the basis of sales turnover of apples. These stores were:

- High turnover store (HTO): Coles Balgowlah
- Medium turnover store (MTO): Coles Rhodes
- Low turnover store (LTO): Coles Mt Druitt

Batlow Co-operative is one of several regular suppliers to the Coles Eastern Creek DC for all three cultivars, but Coles DC does not register supplier source for fruit that is sent to individual supermarkets. In stores apples were transferred from supplier cartons to display stands on the shop floor, and consequently fruit may have come from a selected range of suppliers. Batlow Co-operative label their apples individually and it was therefore known that only Fuji apples from the high turnover store derived from Batlow Co-op. To gain insights about storage conditions of other suppliers (in particular whether they commonly use 1-MCP treatment or not), supplier information from Coles DC was used to contact these suppliers. 1-MCP treatment was used for the Fuji apples in this study. Most, but not all, of the potential suppliers of the other two cultivars used 1-MCP.

Seventy-five apples from each of the three cultivars were purchased at point of sale (on display) in each of the supermarkets, taking random samples from all boxes available. Fuji was no longer sold at Coles Mt Druitt, due to slow turnover in combination with perceived poor quality of this cultivar at that time of year (personal communication from the produce manager at Coles Mt Druitt). Thus, the benchmark study included eight samples (Table 5). Fruit was purchased either one or two days prior to sensory evaluation and stored in cool room facilities at CSIRO North Ryde at 2°C. They were removed from refrigeration the evening before the evaluation, so that all fruit were evaluated at room temperature.

Table 5: Description of samples used in the benchmark study

Sample code	Cultivar	Turnover	Coles store
FJ- HTO	Red Fuji	High	Balgowlah
FJ – MTO	Red Fuji	Medium	Homebush
PL – HTO	Pink Lady	High	Balgowlah
PL – MTO	Pink Lady	Medium	Homebush
PL – LTO	Pink Lady	Low	Mt Druitt
RD – HTO	Red Delicious	High	Balgowlah
RD – MTO	Red Delicious	Medium	Homebush
RD – LTO	Red Delicious	Low	Mt Druitt

2.3.2 Descriptive sensory analysis

The same sensory panel, method of assessment and sensory consensus vocabulary (Table 4) as for the supply chain study was used. The benchmark evaluation was conducted straight after sensory evaluation of time point 3 of the supply chain study and one further training session was conducted to familiarise the panellists with the samples. Then, the panel evaluated the apples in triplicate on three consecutive days. Each day, the panellists evaluated all eight samples of the benchmark study.

2.3.3 Instrumental measurements

The visual quality assessments and physico-chemical measurements were the same as for the supply chain part of the study. The collection of instrumental data FFP and Brix % was done in parallel with sensory evaluation on the same apples.

2.4 Schedule of timings

Sensory and instrumental data were collected as per Table 6.

Table 6: Time points for sensory and instrumental evaluations

Activity / Time Point	From Batlow Fruit Co-operative to Coles DC	From DC to retail store	Pick-up from Coles store by CSIRO- initial instrumental measurements	Storage at CSIRO	Sensory and instrumental evaluation
Time point 1	21 May 09	22 May 09	22 May 09	10 days	1-3 Jun 09
Time point 2	6 Aug 09	7 Aug 09	7 Aug 09	10 days	17-19 Aug 09
Time point 3	22 Oct 09	23 Oct 09	23 Oct 09	10 days	2-4 Nov 09
Time point 4	7 Jan 10	8 Jan 10	8 Jan 10	10 days	18-20 Jan 10
Benchmark Study	n/a	n/a	n/a	n/a	6-10 Nov 09

2.5 Data analysis

The data were analysed using the statistical software package SPSS (version 17.0.0, 2008). A value of $p<0.05$ was used as a criterion to determine statistically significant differences.

Statistical analyses were carried out for each time point separately, and then across time points.

For each time point and for the benchmark study, descriptive sensory evaluation data were analysed using Analysis of Variance with product (N = 12 for supply chain, and N = 8 for bench mark study) and assessor (N = 10) as main fixed treatment factors. Estimated means were produced along with standard errors of difference (SED). Twice the SED corresponds to a Least Significant Difference (LSD), which is an indication of the minimum value necessary for significant differences between sample means. Fisher's Least Significant Differences (LSD) test was used as a posthoc test to determine which pairs of samples were significantly different from each other.

A three-way ANOVA was also carried out for each time point of the supply chain study to statistically compare the effects of cultivar, cooling method and storage temperature on the sensory attributes of the samples. A two-way ANOVA was carried out for the benchmark study to statistically compare the effect of cultivar and supermarket on the sensory attributes of the samples.

Visual data was recorded as presence or absence on each fruit used and then tabulated as a percent value.

ANOVA was carried out to determine if there were statistically significant differences between the samples for the instrumental measurements FFP and Brix %.

Statistical comparisons across time points were carried out on mean sensory data, using time point, cultivar, cooling method and storage temperature as fixed factors. Two-way interactions were included in the model.

Principal component analysis (PCA) was conducted on the sensory data of all four time points using Unscrambler (version 9.1, 2004) to summarise the similarities and differences across the samples.

Correlations between sensory attributes and the physico-chemical measurements were calculated using Pearson's correlation coefficients. These analyses took the mean data for each sample at each time point and used the data from the supply chain and benchmark study.

3. RESULTS

3.1 Sensory and instrumental quality of apples as a function of selected supply chain factors

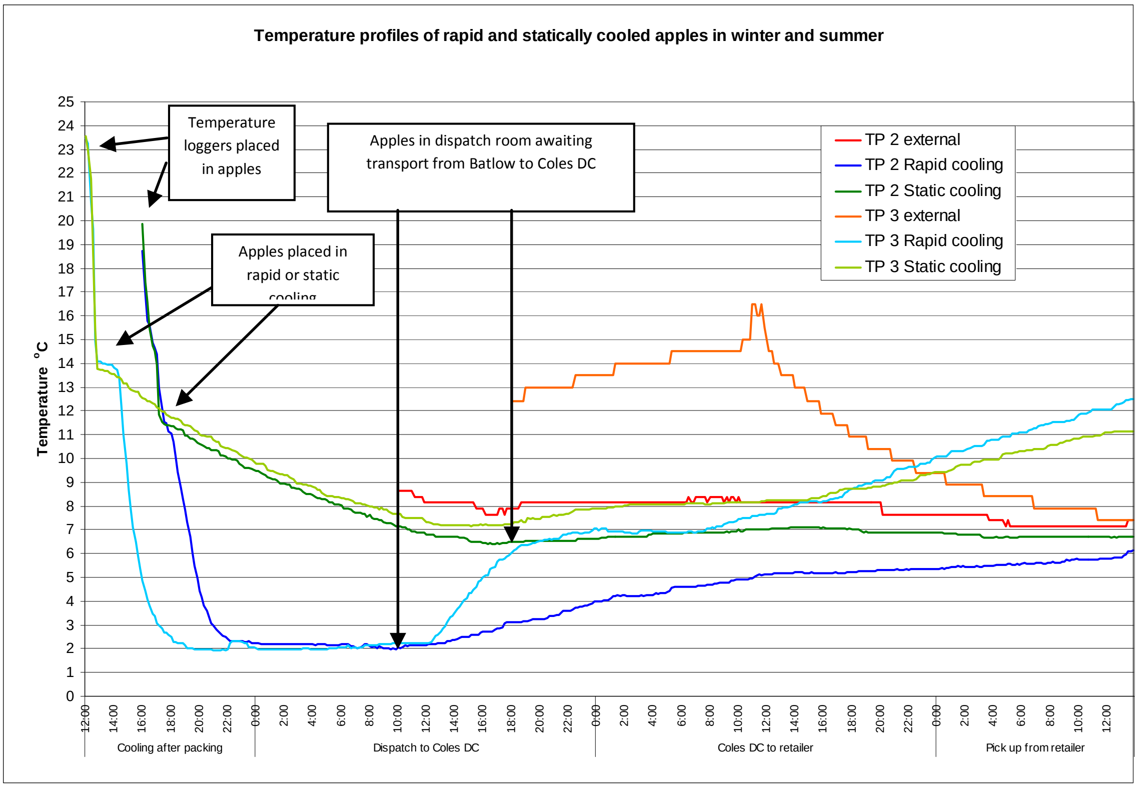
3.1.1 Temperature from samples throughout supply chain.

Temperature logging devices were placed in the core area of apples at the pack house. Monitoring the internal core temperature of the apples during the supply chain provided data on the flesh temperature during rapid cooling compared to static cooling. The temperature data also provided information on any temperature abuse during transport of the apples.

The results show that rapid cooling was effective in decreasing the core temperature of the apples rapidly compared to static cooling. Apple temperatures of rapidly cooled apples decreased to 2°C in approximately 4 hrs while statically cooled apples reached a temperature of approximately 7°C in 24 hours.

The higher environment (pallet) temperature experienced during time point 3 (November) resulted in a gradual increase in the internal apple temperature to 12°C even when the pallet was placed in cooler temperatures. These higher temperatures suggest that maintaining temperatures below 10°C during transport is not always possible with increased external temperatures experienced during summer months.

Figure 2: Temperature profile of apples at time point 2 (August) and 3 (November) (red and orange line are outside temperatures at time point 2 and 3, respectively)



3.1.2 Sensory quality

<u>Time point 1 (June '09)</u>

- All sensory attributes significantly discriminated between the 12 samples, with the exception of *floral odour, sweet taste* and *sweet aftertaste* (Table 7a and 7b).
- There were significant differences between the three apple cultivars in 16 of the 23 attributes, relating to appearance, odour, texture / mouthfeel, flavour and aftertaste / afterfeel attributes. Fuji was characterised by a relatively high *crispiness, juiciness, crunchiness, green odour* and *green colour* and a low *flouriness* and *acid taste*. Pink Lady was characterised by relatively high *crispiness, juiciness, crunchiness, firmness, flavour impact, green flavour, acid taste* and *acid aftertaste* and relatively low *skin toughness*. Red Delicious was characterised by a relatively high *earthy odour, earthy flavour*, and *flouriness,* a slight *bitter taste* and a low intensity of *green flavour*, *crispness, juiciness, crunchiness* and *firmness* (Table 7c).
- The storage temperature during the 10 day storage period had a larger effect on the sensory characteristics than the cooling method.
- Ambient versus chilled storage for 10 days effected 16 sensory attributes. Apples stored ambient (20°C) were more intense in *cream colour, odour impact, pear odour* and *flavour, earthy odour* and *flavour* and *flouriness*, whereas apples stored chilled (5°C) were more intense in *green colour, odour* and *flavour, crispy, juicy, crunchy, firm* and *acidic taste* and *aftertaste* (Table 7d).

- The effect of temperature differed for the cultivars for 7 attributes (in statistical terms: there were significant interaction effects between cultivar and temperature). Observation of results in Table 7a and 7b shows that temperature had a larger effect on Red Delicious than on the other two cultivars. Pink Lady was least effected by temperature.
- Statistically significant, but relatively small differences in 5 texture attributes were observed as a result of cooling method. Statically cooled apples were more *crispy, juicy, crunchy, firm* and less *floury* than rapidly cooled apples (Table 7e).

Time point 2 (August '09)

- 17 of 23 sensory attributes significantly discriminated between the 12 samples (Table 8a, Table 8b).
- There were significant differences between the three apple cultivars in 17 of the 23 attributes, relating to appearance, odour, texture / mouthfeel, flavour and aftertaste / afterfeel attributes (see Appendix B).
- Ambient versus chilled storage for 10 days effected 3 texture attributes. Apples stored chilled (5°C) were more *crispy, juicy* and *firm* than apples stored ambient (20°C) (see Appendix B).
- Cooling method had no effect on the sensory characteristics of the apples.
- One significant interaction effect was found; *pear odour* for Red Delicious was higher when stored ambient than chilled, whereas no temperature effect was observed for the other two cultivars.

Time point 3 (October '09)

- 19 of 23 sensory attributes significantly discriminated between the 12 samples (Table 9a, Table 9b).
- There were significant differences between the three apple cultivars in 19 of the 23 attributes relating to appearance, odour, texture / mouthfeel, flavour and aftertaste / afterfeel attributes (see Appendix B).
- Ambient versus chilled storage for 10 days effected 4 texture attributes as well as *cream colour.* Apples stored ambient (20°C) were more intense in *cream colour*, whereas apples stored chilled (5°C) were more *crispy, juicy, crunchy* and *firm* (see Appendix B).
- Cooling method had no effect on the sensory characteristics of the apples.
- Few interaction effects were found. Similar to time point 2, Red Delicious had a stronger *pear odour* when stored ambient than chilled, whereas no temperature effect was observed for the other two cultivars. In addition, *flavour impact* was higher for Pink Lady stored chilled than ambient, whereas no temperature effect was observed for the other two cultivars.

Time point 4 (January '10)

- All sensory attributes significantly discriminated between the 12 samples (Table 10a, Table 10b).
- There were significant differences between the three apple cultivars in 21 of the 23 attributes relating to appearance, odour, texture / mouthfeel, flavour and aftertaste / afterfeel attributes (see Appendix B).
- Ambient versus chilled storage for 10 days effected 3 sensory attributes only. Apples stored ambient (20°C) were more intense in *cream colour and earthy flavour,* whereas apples stored chilled (5°C) were crunchier (see Appendix B). Other texture attributes (*crispiness, juiciness, firmness* and *flouriness*) showed the same patterns as in previous time points but did not reach significance.

- Cooling method had no effect on the sensory characteristics of the apples.
- Few interactions were found. Similar to the other time points, Red Delicious had a stronger *pear odour* when stored ambient than chilled, whereas no temperature effect was observed for the other two cultivars. Red Delicious was lower in *firmness* after ambient storage compared to chilled storage, whereas no temperature effect was observed for the other cultivars.

Table 7a: Mean intensities from descriptive sensory evaluation of apple colour, odour and texture – Time point 1

Sample	APPEARANCE		ODOUR					TEXTURE					
	Cream colour	Green colour	Odour impact	Green	Pear	Floral	Earthy	Crispi-ness	Juici ness	Crunchi ness	Firmness	Flouri-ness	Skin toughness
FJ Rapid 5	20.8	35.4	39.4	44.5	18.5	9.0	7.3	66.8	57.8	53.3	53.9	15.3	43.1
FJ Static 5	23.0	32.7	43.1	43.2	24.2	7.2	9.3	64.6	57.1	50.2	50.8	16.1	45.2
FJ Rapid 20	33.0	29.0	53.1	34.7	40.9	10.4	20.6	54.8	48.1	45.7	45.7	30.6	47.3
FJ Static 20	28.0	27.8	55.1	33.4	47.9	8.7	21.1	48.0	42.8	40.1	40.3	34.0	41.1
PL Rapid 5	14.8	17.2	41.7	36.0	20.1	12.4	7.9	71.4	59.7	62.5	63.5	5.1	36.9
PL Static 5	15.6	19.4	42.6	37.7	28.8	8.9	7.7	71.7	54.1	61.3	61.2	9.6	36.2
PL Rapid 20	16.9	18.0	45.6	39.0	28.1	15.6	4.7	67.1	55.7	59.4	60.9	10.3	35.5
PL Static 20	19.0	14.5	42.7	35.4	27.4	13.8	3.8	70.1	53.6	62.3	60.2	10.8	34.1
RD Rapid 5	20.8	39.5	38.6	38.6	25.8	11.1	15.7	53.5	51.2	39.7	38.4	40.0	57.7
RD Static 5	23.3	34.6	40.3	37.0	22.0	10.7	12.5	44.3	42.1	33.0	32.6	44.0	49.7
RD Rapid 20	26.2	31.9	45.8	29.3	37.3	13.3	20.6	43.5	38.2	30.8	34.8	48.9	51.0
RD Static 20	27.2	28.2	51.6	32.8	40.6	13.6	26.0	35.1	27.8	22.3	23.5	67.3	47.1

Overall sample effect

F-value	4.95	8.98	5.77	1.85	10.52	1.45	8.80	28.95	16.45	36.63	31.58	44.82	8.46
p-value	<0.0001	<0.0001	<0.0001	0.046	<0.0001	ns	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
SED	2.5	2.7	2.3	3.1	2.9		2.5	2.4	2.4	2.3	2.4	2.9	2.5

Effect of design factors (p values)

Cultivar	<0.0001	<0.0001	ns	ns	0.03	ns	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cooling method	ns	ns	ns	ns	ns	ns	ns	0.02	0.001	0.03	0.01	0.01	ns
Temperature	0.001	0.01	<0.0001	0.02	<0.0001	ns	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ns
Cultivar by cooling	ns	ns	ns	ns	ns	ns	ns	0.04	ns	ns	ns	ns	ns
Cultivar by temp	ns	ns	ns	ns	0.00	ns	<0.0001	0.02	0.02	ns	ns	0.01	ns
Cooling by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 7b: Mean intensities from descriptive sensory evaluation of apple flavour, aftertaste and afterfeel – Time point 1

Sample	FLAVOUR				TASTE			AFTERTASTE / AFTERFEEL		
	Flavour Impact	Green	Pear	Earthy	Sweet	Bitter	Acid	Sweet	Acid	Astringent
FJ Rapid 5	48.8	34.7	30.3	11.2	44.2	7.6	9.2	29.1	3.7	12.6
FJ Static 5	49.5	31.9	40.6	12.3	48.4	4.5	7.7	33.4	4.1	9.0
FJ Rapid 20	53.3	24.1	44.9	26.1	49.1	9.0	9.9	36.2	5.5	12.0
FJ Static 20	54.3	20.4	49.3	31.0	49.1	7.4	5.5	35.8	4.6	8.1
PL Rapid 5	63.1	36.1	30.9	7.4	45.7	3.3	39.6	33.2	34.8	16.1
PL Static 5	63.3	43.6	31.3	6.3	41.5	4.8	45.5	26.8	33.1	15.2
PL Rapid 20	62.5	38.2	41.3	9.2	46.3	1.4	37.9	32.9	24.0	9.8
PL Static 20	64.5	32.4	42.4	8.0	48.9	1.8	31.6	32.6	24.0	12.3
RD Rapid 5	46.5	29.8	37.3	24.3	42.6	16.8	5.9	30.0	5.0	15.7
RD Static 5	45.9	24.5	38.9	25.6	45.3	10.6	5.9	35.8	5.3	11.7
RD Rapid 20	47.7	19.8	40.0	36.7	41.0	14.2	5.5	30.5	4.1	12.4
RD Static 20	48.5	11.3	46.3	45.7	43.6	11.5	3.7	34.9	2.1	11.9
Overall sample effect										
F-value	11.69	12.03	4.28	16.65	1.26	6.60	59.11	1.39	44.24	1.86
p-value	<0.0001	<0.0001	<0.0001	<0.0001	ns	<0.0001	<0.0001	ns	<0.0001	0.046
SED	2.2	2.6	2.96	3.2		1.9	2.1		1.9	1.8
Effect of design factors (p values)										
Cultivar	<0.0001	<0.0001	ns	<0.0001	ns	<0.0001	<0.0001	ns	<0.0001	ns
Cooling method	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Temperature	ns	0.00	<0.0001	<0.0001	ns	ns	0.04	ns	0.02	ns
Cultivar by cooling	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar by temp	ns	ns	ns	0.01	ns	ns	ns	ns	0.01	ns
Cooling by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 7c: Mean intensities of significant sensory attributes by cultivar – Time point 1

Cultivar	Cream colour	Green colour	Pear O	Earthy O	Crispi-ness	Juici-ness	Crunchi-ness	Firm-ness	Flouri-ness	Skin tough-ness	Flavour impact	Green flavour	Earthy flavour	Bitter	Acidic	Acidic AT
Fuji	26.2	31.2	32.9	14.5	58.5	51.4	47.3	47.7	24.0	44.2	51.5	27.8	20.2	7.1	8.1	4.5
Pink Lady	16.5	17.3	26.1	6.0	70.1	55.8	61.4	61.4	8.9	35.6	63.3	37.6	7.7	2.8	38.7	29.0
Red Delicious	24.4	33.6	31.4	18.7	44.1	39.8	31.4	32.3	50.0	51.4	47.1	21.3	33.1	13.2	5.2	4.1

Table 7d: Mean intensities of significant sensory attributes by storage temperature – Time point 1

Storage temp	Cream colour	Green colour	Odour impact	Green	Pear	Earthy	Crispi-ness	Juici-ness	Crunchi-ness	Firm-ness	Flouri-ness	Green flavour	Pear flavour	Earthy flavour	Acidic	Acidic AT
5 degrees	19.7	29.8	40.9	39.5	23.2	10.1	62.0	53.7	50.0	50.0	21.7	33.4	34.9	14.5	19.0	14.3
20 degrees	25.1	24.9	49.0	34.1	37.0	16.1	53.1	44.4	43.4	44.2	33.6	24.4	44.0	26.1	15.7	10.7

Table 7e: Mean intensities of significant sensory attributes by cooling method – Time point 1

Cooling method	Crispiness	Juiciness	Crunchiness	Firmness	Flouriness
Rapid	59.5	51.8	48.6	49.5	25.0
Static	55.6	46.2	44.9	44.8	30.3

Table 8a: Mean intensities from descriptive sensory evaluation of apple colour, odour and texture – Time point 2

Sample	APPEARANCE		ODOUR					TEXTURE					
	Cream colour	Green colour	Odour impact	Green	Pear	Floral	Earthy	Crispiness	Juici ness	Crunchi ness	Firmness	Flouriness	Skin toughness
FJ Rapid 5	21.2	23.1	40.0	41.0	11.0	0.8	1.8	60.6	55.6	53.4	52.8	10.3	40.5
FJ Static 5	18.9	22.1	39.4	41.4	7.3	1.6	1.7	65.0	57.7	57.2	52.8	9.8	39.3
FJ Rapid 20	20.2	24.1	41.0	40.2	14.0	1.5	2.7	57.5	53.8	53.8	53.2	13.0	40.5
FJ Static 20	18.7	27.9	43.0	42.2	10.6	0.8	3.5	55.4	49.1	48.1	46.1	14.6	40.5
PL Rapid 5	8.4	16.9	40.7	36.3	21.4	2.0	0.1	60.7	57.0	55.7	57.6	9.4	37.6
PL Static 5	6.9	12.0	40.7	33.0	18.0	2.8	0.0	60.8	52.8	51.7	53.6	14.9	38.7
PL Rapid 20	10.8	13.0	35.7	30.1	15.3	1.3	0.7	58.7	49.1	52.9	54.3	11.3	40.3
PL Static 20	12.2	15.4	40.9	35.2	13.0	1.9	0.6	58.7	52.5	54.5	54.0	8.3	38.2
RD Rapid 5	17.1	21.4	39.2	33.8	13.2	0.5	4.1	57.9	51.7	48.6	49.5	15.3	55.1
RD Static 5	19.9	21.9	39.2	37.4	12.3	1.3	3.2	59.9	52.1	46.2	47.6	16.8	53.4
RD Rapid 20	21.9	22.8	44.9	37.1	20.2	2.7	3.6	51.9	48.0	44.8	45.2	20.3	55.0
RD Static 20	20.9	23.0	42.6	38.2	17.0	1.8	3.6	54.0	47.5	44.1	45.3	24.0	57.1

Overall sample effect

F-value	8.19	6.83	1.26	2.44	3.40	1.64	2.52	3.35	2.98	4.84	3.97	6.57	11.37
p-value	< 0.0001	< 0.0001	ns	0.007	0.0001	ns	0.005	0.0001	0.001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SED	2.6	2.6		3.4	3.2		1.3	2.7	2.8	2.8	2.9	2.6	3.3

Effect of design factors (p values)

Cultivar	< 0.0001	< 0.0001	ns	0.004	0.008	ns	0.001	0.032	0.019	< 0.0001	< 0.0001	0.004	< 0.0001
Cooling method	ns	ns	ns	ns	0.097	ns	ns	ns	ns	ns	ns	ns	ns
Temperature	ns	ns	ns	ns	ns	ns	ns	0.000	0.000	ns	0.05	ns	ns
Cultivar by cooling	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar by temp	ns	ns	ns	ns	0.017	ns	ns	ns	ns	ns	ns	ns	ns
Cooling by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 8b: Mean intensities from descriptive sensory evaluation of apple flavour, aftertaste and afterfeel – Time point 2

Sample	FLAVOUR				TASTE			AFTERTASTE / AFTERFEEL		
	Flavour Impact	Green	Pear	Earthy	Sweet	Bitter	Acid	Sweet	Acid	Astringent
FJ Rapid 5	45.1	33.4	24.3	3.5	37.3	1.8	8.8	26.0	3.2	9.8
FJ Static 5	45.9	35.3	22.9	3.8	40.2	1.0	7.1	25.8	3.1	9.5
FJ Rapid 20	45.4	36.3	22.9	3.1	39.3	1.3	6.7	25.9	2.2	6.7
FJ Static 20	41.3	33.5	22.4	4.3	35.5	3.2	5.4	22.4	3.5	8.5
PL Rapid 5	56.7	35.1	27.5	0.1	42.6	0.6	35.3	29.9	27.6	10.4
PL Static 5	56.2	30.7	32.3	0.2	44.3	1.0	32.9	27.0	24.6	8.9
PL Rapid 20	50.9	33.0	28.4	0.1	44.4	1.1	27.1	31.3	17.8	8.4
PL Static 20	54.7	34.0	26.1	0.0	42.5	0.4	29.9	26.5	23.3	10.1
RD Rapid 5	45.3	31.7	25.4	3.6	39.0	5.7	7.1	27.5	4.1	11.3
RD Static 5	45.6	34.5	23.4	4.3	37.2	4.3	8.9	24.0	4.1	12.5
RD Rapid 20	48.0	33.1	28.4	7.0	38.1	5.8	6.5	27.3	2.7	9.9
RD Static 20	42.0	30.3	25.9	5.3	36.7	6.8	5.9	26.0	3.5	10.3
Overall sample effect										
F-value	9.13	0.61	1.27	4.45	2.06	6.91	30.23	1.25	30.38	0.89
p-value	< 0.0001	ns	ns	< 0.0001	0.024	< 0.0001	< 0.0001	ns	< 0.0001	ns
SED	2.5			1.6	3.0	1.2	3.1		2.6	
Effect of design factors (p values)										
Cultivar	< 0.0001	ns	ns	< 0.0001	0.008	< 0.0001	< 0.0001	ns	< 0.0001	ns
Cooling method	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Temperature	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar by cooling	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cooling by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 9a: Mean intensities from descriptive sensory evaluation of apple colour, odour and texture – Time point 3

Sample	APPEARANCE		ODOUR					TEXTURE					
	Cream colour	Green colour	Odour impact	Green	Pear	Floral	Earthy	Crispiness	Juici ness	Crunchi ness	Firmness	Flourines s	Skin toughness
FJ Rapid 5	18.0	13.7	45.7	38.4	22.0	1.4	1.9	61.0	58.4	53.5	53.6	10.3	43.4
FJ Static 5	21.4	11.5	44.8	36.1	24.2	2.1	2.3	63.4	63.5	58.5	54.1	11.0	39.1
FJ Rapid 20	21.3	11.3	46.3	38.8	23.2	1.4	4.3	53.9	52.6	50.3	49.4	9.5	42.5
FJ Static 20	24.0	16.9	46.2	36.8	22.0	1.4	2.7	53.7	51.8	49.3	48.2	11.9	42.1
PL Rapid 5	12.4	7.4	45.8	30.4	32.3	3.4	1.5	56.3	54.1	52.0	51.7	15.1	42.3
PL Static 5	18.2	6.0	46.2	24.4	33.3	2.9	5.9	51.7	51.2	47.0	47.2	22.0	40.1
PL Rapid 20	23.1	6.7	46.1	28.4	27.9	3.4	1.2	51.0	46.9	45.1	48.1	20.0	40.1
PL Static 20	22.1	4.8	42.8	28.0	30.1	1.4	2.1	48.4	43.6	43.3	46.7	20.8	43.7
RD Rapid 5	9.7	22.9	42.4	40.0	14.5	2.0	2.4	61.1	55.8	54.8	54.9	12.1	62.6
RD Static 5	10.0	23.5	42.9	41.8	15.6	4.2	3.0	59.7	55.9	52.4	53.2	13.9	60.4
RD Rapid 20	10.8	25.4	44.5	43.0	21.4	2.3	3.1	55.5	51.8	47.4	51.3	18.7	62.2
RD Static 20	10.8	26.0	48.3	42.5	26.1	2.2	3.2	60.1	51.9	53.8	49.9	16.4	62.5
Overall sample effect													
F-value	8.81	18.40	0.61	5.95	4.84	1.64	0.91	3.96	5.18	2.95	1.43	3.59	13.34
p-value	< 0.0001	< 0.0001	ns	< 0.0001	< 0.0001	ns	ns	< 0.0001	< 0.0001	0.001	ns	0.000	< 0.0001
SED	2.7	2.6		3.9	3.9			3.3	3.1	3.4		3.3	3.8
Effect of design factors (p values)													
Cultivar	< 0.0001	< 0.0001	ns	< 0.0001	< 0.0001	ns	ns	0.000	< 0.0001	0.003	ns	0.006	< 0.0001
Cooling method	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Temperature	0.004	ns	ns	ns	ns	ns	ns	0.001	< 0.0001	0.002	0.027	ns	ns
Cultivar by cooling	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar by temp	ns	ns	ns	ns	0.032	ns	ns	ns	ns	ns	ns	ns	ns
Cooling by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 9b: Mean intensities from descriptive sensory evaluation of apple flavour, aftertaste and afterfeel – Time point 3

Sample	FLAVOUR				TASTE			AFTERTASTE / AFTERFEEL		
	Flavour Impact	Green	Pear	Earthy	Sweet	Bitter	Acid	Sweet	Acid	Astringent
FJ Rapid 5	55.1	28.9	39.6	1.3	47.9	0.9	4.4	29.5	0.9	1.9
FJ Static 5	56.2	25.9	42.5	3.8	50.8	1.9	3.7	29.6	2.4	3.6
FJ Rapid 20	55.0	26.6	37.2	2.1	49.3	2.0	4.4	30.4	1.4	2.9
FJ Static 20	50.7	27.4	39.1	5.4	44.3	2.7	1.9	28.7	1.4	4.9
PL Rapid 5	61.5	26.6	40.1	3.0	43.5	0.4	36.9	23.5	21.2	11.1
PL Static 5	59.8	22.1	38.8	9.4	39.1	4.8	31.3	21.2	20.0	8.2
PL Rapid 20	56.4	22.7	34.3	2.3	42.9	0.6	32.3	21.2	17.6	10.4
PL Static 20	50.1	21.3	34.5	4.1	36.6	3.4	25.7	19.0	16.0	8.3
RD Rapid 5	48.1	36.6	26.7	7.6	31.5	11.4	6.4	14.7	3.9	9.0
RD Static 5	49.0	38.5	29.7	6.4	36.5	7.7	6.0	17.4	2.3	9.8
RD Rapid 20	49.9	42.5	24.6	12.1	31.5	16.2	5.6	15.6	5.5	12.7
RD Static 20	52.7	42.7	26.4	11.3	34.0	12.5	6.2	18.2	3.4	9.3
Overall sample effect										
F-value	3.25	8.55	4.08	2.43	6.26	12.99	27.55	6.81	20.99	5.60
p-value	0.000	< 0.0001	< 0.0001	0.007	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SED	3.2	4.0	4.4	3.2	3.7	2.1	3.6	3.1	2.5	2.0
Effect of design factors (p values)										
Cultivar	0.001	< 0.0001	< 0.0001	0.003	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Cooling method	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Temperature	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar by cooling	ns	ns	ns	ns	ns	0.011	ns	ns	ns	ns
Cultivar by temp	0.024	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cooling by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 10a: Mean intensities from descriptive sensory evaluation of apple colour, odour and texture – Time point 4

Sample	APPEARANCE		ODOUR					TEXTURE					
	Cream colour	Green colour	Odour impact	Green	Pear	Floral	Earthy	Crispiness	Juici ness	Crunchiness	Firmness	Flouriness	Skin toughness
FJ Rapid 5	21.7	19.8	48.7	40.4	12.3	1.3	3.8	60.9	58.1	55.5	55.4	17.9	42.7
FJ Static 5	23.4	17.2	48.9	39.6	17.6	1.5	1.8	59.3	57.1	51.5	48.6	20.4	43.7
FJ Rapid 20	22.8	20.5	46.6	40.1	14.3	4.0	2.3	59.5	51.0	53.3	52.6	18.6	46.2
FJ Static 20	30.2	16.1	48.2	34.4	17.5	2.8	3.7	55.6	54.2	51.1	55.0	21.0	46.1
PL Rapid 5	11.1	5.4	45.9	22.9	25.0	5.7	1.2	59.6	56.8	55.1	59.2	20.2	38.9
PL Static 5	11.1	6.2	47.4	24.7	24.3	6.5	1.2	63.7	56.1	59.7	63.8	16.6	37.8
PL Rapid 20	15.1	5.7	48.4	28.7	20.8	3.9	0.6	63.0	57.2	56.9	60.3	17.1	43.5
PL Static 20	15.6	3.9	48.4	24.7	22.1	3.1	1.6	60.9	53.0	55.5	61.7	17.9	45.5
RD Rapid 5	9.6	29.6	49.6	38.0	17.9	3.2	3.3	58.8	55.0	47.8	51.0	29.4	63.7
RD Static 5	8.5	31.1	42.4	35.9	16.4	2.6	4.3	60.2	52.3	50.2	52.6	29.0	64.0
RD Rapid 20	9.1	27.6	53.4	28.6	30.2	2.2	4.5	53.2	51.7	42.5	45.8	37.3	65.2
RD Static 20	10.4	28.2	54.0	30.9	26.3	4.9	6.4	51.9	51.4	42.2	44.5	37.0	64.7

Overall sample effect

F-value	16.83	28.24	2.34	7.62	5.12	3.07	1.82	4.90	1.81	7.46	10.83	7.71	23.81
p-value	< 0.0001	< 0.0001	0.01	< 0.0001	< 0.0001	<0.01	0.05	< 0.0001	0.05	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SED	2.5	2.7	2.8	3.3	3.3	1.3	1.8	2.3	2.7	2.8	2.7	3.9	3.1

Effect of design factors (p values)

Cultivar	< 0.0001	< 0.0001	ns	< 0.0001	0.02	0.03	0.04	0.02	ns	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Cooling method	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Temperature	0.02	ns	ns	ns	ns	ns	ns	ns	ns	0.04	ns	ns	ns
Cultivar by cooling	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar by temp	ns	ns	ns	ns	0.02	ns	ns	ns	ns	ns	0.03	ns	ns
Cooling by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Table 10b: Mean intensities from descriptive sensory evaluation of apple flavour, aftertaste and afterfeel – Time point 4

Sample	FLAVOUR				TASTE			AFTERTASTE / AFTERFEEL		
	Flavour Impact	Green	Pear	Earthy	Sweet	Bitter	Acid	Sweet	Acid	Astringent
FJ Rapid 5	53.6	30.7	26.4	6.9	38.4	7.0	9.2	26.2	5.1	13.5
FJ Static 5	53.8	27.2	30.9	4.4	45.4	6.0	6.1	30.5	2.7	13.5
FJ Rapid 20	51.2	29.7	24.2	9.4	40.7	8.5	7.6	26.9	4.3	15.0
FJ Static 20	53.5	26.8	30.4	7.3	43.8	6.8	6.4	28.9	4.5	10.7
PL Rapid 5	63.6	20.6	33.9	1.2	55.3	1.6	39.1	35.9	26.2	15.4
PL Static 5	65.5	24.0	27.5	0.5	48.6	0.6	41.0	29.8	27.5	16.1
PL Rapid 20	64.3	21.4	31.6	0.4	51.0	0.7	37.8	33.3	27.0	16.0
PL Static 20	60.1	19.2	31.2	3.1	48.2	1.9	35.9	34.7	22.9	16.0
RD Rapid 5	50.6	34.1	21.6	6.7	30.1	22.9	7.8	18.3	6.0	25.0
RD Static 5	46.3	32.0	19.1	7.3	27.9	21.9	6.8	19.1	5.3	28.6
RD Rapid 20	46.9	30.2	23.8	11.6	31.2	22.1	5.7	16.7	4.8	27.6
RD Static 20	50.1	38.6	20.8	12.2	33.0	29.4	5.5	20.3	3.9	28.3
Overall sample effect										
F-value	11.56	6.30	4.57	8.94	19.71	39.25	101.22	20.17	51.58	20.39
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SED	2.8	3.3	3.2	1.9	2.9	2.3	2.2	2.1	2.1	2.1
Effect of design factors (p values)										
Cultivar	< 0.0001	< 0.0001	0.01	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Cooling method	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Temperature	ns	ns	ns	0.03	ns	ns	ns	ns	ns	ns
Cultivar by cooling	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cultivar by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cooling by temp	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

3.1.3 Visual and instrumental quality

External and internal visual quality was assessed at each time point. Incidence of quality defects was low and mostly comparable between time points. Quality of the intact apple was good, with only a slightly higher percentage of bruises observed for Pink Lady at time point 3. Visual quality once cut open was good for all apples, only core rot of ambient stored Red Delicious apples at time point 3 was observed relatively more frequently (up to 37%). Tables with incidence of quality defects at each time point are provided in Appendix C.

<u>Time point 1 (May '09)</u>

Fruit Firmness Pressure:

- Cultivars differed in firmness (Table 11). Pink Lady was the firmest, followed by Fuji and Red Delicious.
- Storage temperature effected firmness (FFP). Apples stored in ambient conditions were lower in firmness (FFP) than apples stored chilled.
- Cooling method effected firmness (FFP). Rapidly cooled apples had a higher FFP than statically cooled apples.
- The effect of cooling method differed depending on cultivar and depending on storage temperature Cooling method effected Red Delicious apples but not the other two cultivars. Statically cooled apples experienced greater softening than rapidly cooled apples when they were stored at 20°C, whereas they did not differ in firmness (FFP) when they were stored at 5°C for 10 days.
- Pre-storage rapidly cooled Fuji was firmer than statically cooled Fuji.
- Comparing the three firmness measurements taken at different points along the supply chain (at Batlow, before and after 10 days of storage), a decline in firmness was observed, particularly for Fuji and Red Delicious stored at ambient temperatures for 10 days (Figure 3). Firmness continued to meet Coles' quality specifications after 10 days storage for Fuji and Pink Lady, but not for Red Delicious, particularly when stored ambient.

Brix %:

- Cultivars differed in Brix % (Table 11). Red Delicious was higher in Brix % than Fuji apples.
- Storage temperature did not effect Brix %.
- Cooling method effected Brix %. Rapidly cooled apples were higher in Brix % than statically cooled apples.
- Brix % for Red Delicious was lower when measured at Batlow and after storage than before storage. However, it displayed a large variation and did not differ for the other cultivars (Table 11).

<u>Time point 2 (August '09)</u>

Fruit Firmness Pressure:

- Cultivars differed in firmness (Table 12). Pink Lady was firmer, followed by Fuji and Red Delicious, which was the least firm.
- Storage temperature did not affect apple firmness (FFP).

- Cooling method effected firmness (FFP). Rapidly cooled apples had a higher FFP than statically cooled apples.
- The effect of cooling method differed depending on cultivar; cooling method effected Fuji stored at ambient temperatures, but not the other two cultivars.
- Pre-storage rapidly cooled Fuji was higher in FFP than statically cooled Fuji
- All samples exceeded firmness specifications from Coles', despite some small decreases in firmness from Batlow measurements to those taken following 10 days storage (Figure 3).

Brix %:

- Cultivars differed in Brix % (Table 12). Pink Lady was higher in Brix % than Red Delicious and Fuji.
- Storage temperature and cooling method did not affect Brix %.
- Brix % measured at Batlow was slightly lower than Brix % measured after 10 days of storage (Table 12).

<u>Time point 3 (October '09)</u>

Fruit Firmness Pressure:

- Cultivars differed in FFP (Table 13). Pink Lady had the highest FFP, followed by Red Delicious and Fuji apples had the lowest FFP.
- Storage temperature and cooling method did not affect FFP, nor were there any significant interaction effects.
- Pre-storage rapidly cooled Pink Lady was higher in FFP than statically cooled Pink Lady.
- All samples exceeded firmness specifications from Coles', despite some small decreases in firmness from Batlow measurements to those taken following 10 days storage (Figure 3).

Brix %:

- Cultivars differed in Brix % (Table 13). Fuji was highest and Red Delicious was lowest in Brix %.
- Storage temperature and cooling method did not affect Brix %.
- Brix % measured at Batlow, before and after 10 days of storage was similar (Table 13).

<u>Time point 4 (January '10)</u>

Fruit Firmness Pressure:

- Cultivars differed in firmness (Table 14). Pink Lady had the highest FFP, followed by Fuji and Red Delicious apples had the lowest FFP.
- Storage temperature and cooling method did not affect firmness (FFP), nor were there any significant interaction effects.
- Pre-storage cooling method had no effect on FFP.
- All samples exceeded firmness specifications from Coles'. Firmness did not change from Batlow measurements to those taken following 10 days storage (Figure 3).

Brix %:

- Cultivars differed in Brix % (Table 14). Pink Lady was highest and Red Delicious was lowest in Brix %.
- Storage temperature effected Brix %. Apples stored ambient for 10 days were slightly higher in Brix % than apples stored chilled for 10 days. This was particularly the case for Fuji apples.
- Cooling method did not affect Brix %.
- Brix % measured at Batlow, before and after 10 days of storage was similar (Table 14).

Table 11: Fruit Firmness Pressure and Brix % of samples measured after removal from cool room, upon arrival at CSIRO and after 10 days of storage – Time point 1

Fruit Firmness Pressure (in kg/N)

After removal from coolroom (at Batlow)		After rapid or static cooling (upon arrival at CSIRO)				After 10 days of storage at 5° or 20°C (at CSIRO)			
Sample	**Mean**	**Sample**	**Mean**		**SD**	**Sample**	**Mean**		**SD**
FJ	7.7	FJ Rapid	7.0	b	0.8	FJ Rapid 5	7.0	d	0.9
		FJ Static	6.6	c	0.4	FJ Static 5	7.0	d	0.5
						FJ Rapid 20	6.4	e	0.6
						FJ Static 20	6.1	ef	0.5
PL	8.8	PL Rapid	8.3	a	0.6	PL Rapid 5	8.2	ab	0.8
		PL Static	8.1	a	1.2	PL Static 5	8.6	a	0.7
						PL Rapid 20	8.0	bc	0.7
						PL Static 20	7.8	c	0.9
RD	7.5	RD Rapid	6.7	c	0.4	RD Rapid 5	6.0	ef	0.8
		RD Static	6.6	c	0.4	RD Static 5	5.8	fg	0.8
						RD Rapid 20	5.5	g	0.8
						RD Static 20	4.6	h	0.7
		F value	34.4			F value	79.8		
		P value	< 0.0001			P value	< 0.0001		

°Brix

After removal from coolroom (at Batlow)		After rapid or static cooling (upon arrival at CSIRO)				After 10 days of storage at 5° or 20°C (at CSIRO)			
Sample	**Mean**	**Sample**	**Mean**		**SD**	**Sample**	**Mean**		**SD**
FJ	14.6	FJ Rapid	14.5	ab	1.1	FJ Rapid 5	14.5	cde	0.9
		FJ Static	14.1	b	1.6	FJ Static 5	14.7	bcde	0.9
						FJ Rapid 20	14.1	e	1.2
						FJ Static 20	14.6	cde	1.2
PL	14.7	PL Rapid	14.9	a	0.8	PL Rapid 5	15.0	bc	0.9
		PL Static	14.1	bc	1.0	PL Static 5	14.6	cde	1.2
						PL Rapid 20	14.6	bcde	1.3
						PL Static 20	14.7	bcd	1.0
RD	14.9	RD Rapid	14.4	ab	1.2	RD Rapid 5	15.7	a	1.6
		RD Static	13.5	c	0.7	RD Static 5	15.3	ab	1.6
						RD Rapid 20	14.6	cde	1.7
						RD Static 20	14.2	de	1.1
		F value	4.1			F value	3.7		
		P value	0.002			P value	< 0.0001		

* Samples within the same column grouped by the same letter were not significantly different

Table 12: Fruit Firmness Pressure and Brix % of samples measured after removal from cool room, upon arrival at CSIRO and after 10 days of storage – Time point 2

Fruit Firmness Pressure (in kg/N)									
After removal from coolroom (at Batlow)		**After rapid or static cooling (upon arrival at CSIRO)**				**After 10 days of storage at 5° or 20°C (at CSIRO)**			
Sample	**Mean**	**Sample**	**Mean**		**SD**	**Sample**	**Mean**		**SD**
FJ	7.5	FJ Rapid	7.3	b	0.6	FJ Rapid 5	7.4	bc	0.7
		FJ Static	6.8	c	0.5	FJ Static 5	7.3	cd	0.5
						FJ Rapid 20	7.6	b	0.4
						FJ Static 20	6.8	f	0.5
PL	9.1	PL Rapid	8.4	a	0.6	PL Rapid 5	8.7	a	0.7
		PL Static	8.2	a	0.5	PL Static 5	8.6	a	0.5
						PL Rapid 20	8.7	a	1
						PL Static 20	8.8	a	0.7
RD	7.7	RD Rapid	7.1	bc	0.5	RD Rapid 5	6.9	ef	0.3
		RD Static	7.0	bc	0.5	RD Static 5	7.2	cde	0.4
						RD Rapid 20	7	def	0.4
						RD Static 20	7	def	0.4
		F value	34.4			F value	52.8		
		P value	< 0.0001			P value	< 0.0001		

°Brix									
After removal from coolroom (at Batlow)		**After rapid or static cooling (upon arrival at CSIRO)**				**After 10 days of storage at 5° or 20°C (at CSIRO)**			
Sample	**Mean**	**Sample**	**Mean**		**SD**	**Sample**	**Mean**		**SD**
FJ	15.0	FJ Rapid	14.8	cd	0.9	FJ Rapid 5	15.6	ef	1.0
		FJ Static	14.8	cd	1.3	FJ Static 5	15.6	ef	0.9
						FJ Rapid 20	15.9	de	0.8
						FJ Static 20	15.4	f	1.3
PL	16.1	PL Rapid	15.9	ab	0.8	PL Rapid 5	16.9	ab	0.9
		PL Static	16.3	a	0.7	PL Static 5	17.0	a	0.9
						PL Rapid 20	16.5	bc	0.7
						PL Static 20	16.8	ab	0.7
RD	14.6	RD Rapid	14.4	d	0.8	RD Rapid 5	15.7	def	0.9
		RD Static	15.4	bc	1.2	RD Static 5	15.6	ef	0.7
						RD Rapid 20	15.8	def	0.8
						RD Static 20	16.1	cd	0.9
		F value	8.0			F value	12.6		
		P value	<0.0001			P value	< 0.0001		

* Samples within the same column grouped by the same letter were not significantly different

Table 13: Fruit Firmness Pressure and Brix % of samples measured after removal from cool room, upon arrival at CSIRO and after 10 days of storage – Time point 3

Fruit Firmness Pressure (in kg/N)									
After removal from coolroom (at Batlow)		After rapid or static cooling (upon arrival at CSIRO)				After 10 days of storage at 5° or 20°C (at CSIRO)			
Sample	Mean	Sample	Mean		SD	Sample	Mean		SD
FJ	7.4	FJ Rapid	7.0	c	0.9	FJ Rapid 5	6.9	d	0.6
		FJ Static	6.9	c	0.6	FJ Static 5	6.8	d	0.4
						FJ Rapid 20	6.8	d	0.8
						FJ Static 20	7.0	d	0.8
PL	9.7	PL Rapid	9.5	a	1.0	PL Rapid 5	8.9	ab	0.8
		PL Static	8.8	b	1.3	PL Static 5	8.7	b	1.0
						PL Rapid 20	9.0	ab	0.8
						PL Static 20	9.1	a	1.0
RD	7.9	RD Rapid	7.3	c	0.4	RD Rapid 5	7.4	c	0.4
		RD Static	7.4	c	0.4	RD Static 5	7.4	c	0.5
						RD Rapid 20	7.5	c	0.4
						RD Static 20	7.5	c	0.6
		F value	24.5			F value	62.3		
		P value	< 0.0001			P value	< 0.0001		

°Brix									
After removal from coolroom (at Batlow)		After rapid or static cooling (upon arrival at CSIRO)				After 10 days of storage at 5° or 20°C (at CSIRO)			
Sample	Mean	Sample	Mean		SD	Sample	Mean		SD
FJ	16.0	FJ Rapid	16.4	a	0.9	FJ Rapid 5	16.4	ab	1.5
		FJ Static	16.7	a	1.3	FJ Static 5	16.7	a	1.0
						FJ Rapid 20	16.4	ab	1.2
						FJ Static 20	16.6	ab	1.2
PL	15.8	PL Rapid	16.0	a	0.8	PL Rapid 5	16.0	bc	1.2
		PL Static	15.7	a	0.7	PL Static 5	15.7	cd	1.1
						PL Rapid 20	16.1	abc	1.2
						PL Static 20	15.4	de	1.0
RD	14.4	RD Rapid	14.7	b	0.8	RD Rapid 5	14.7	f	0.9
		RD Static	15.0	b	1.2	RD Static 5	15.0	ef	0.9
						RD Rapid 20	14.7	f	1.0
						RD Static 20	14.7	f	0.9
		F value	6.5			F value	13.5		
		P value	<0.0001			P value	< 0.0001		

* Samples within the same column grouped by the same letter were not significantly different

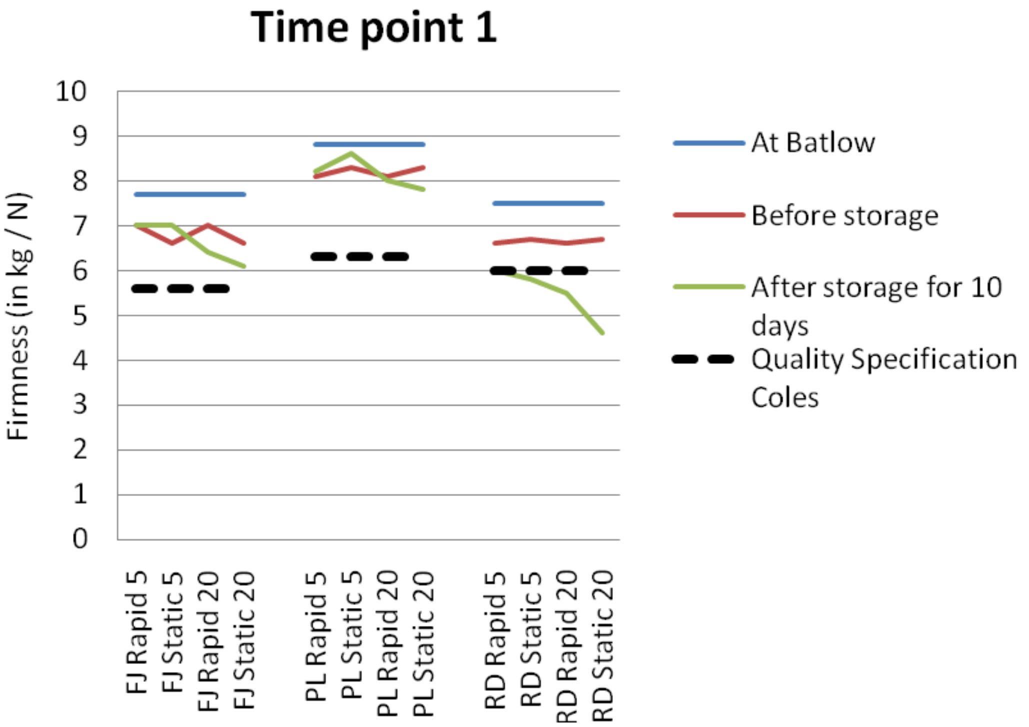
Table 14: Fruit Firmness Pressure and Brix % of samples measured after removal from cool room, upon arrival at CSIRO and after 10 days of storage – Time point 4

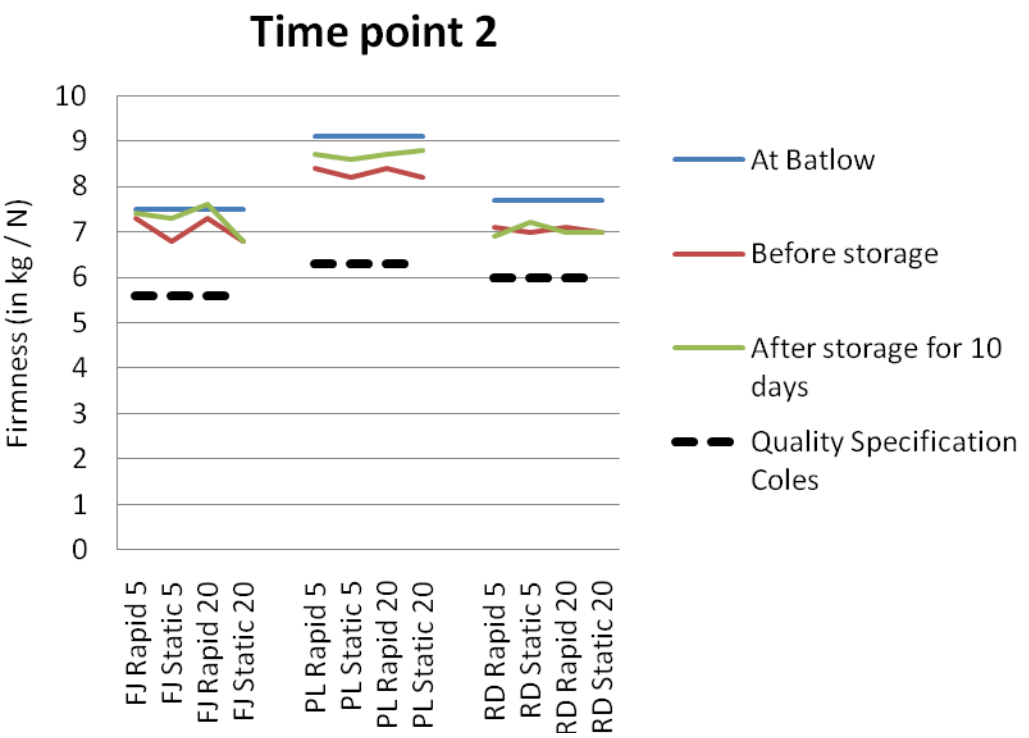
Fruit Firmness Pressure (in kg/N)										
After removal from coolroom (at Batlow)			After rapid or static cooling (upon arrival at CSIRO)				After 10 days of storage at 5° or 20°C (at CSIRO)			
Sample	Mean		Sample	Mean		SD	Sample	Mean		SD
FJ	8.2		FJ Rapid	7.7	b	0.5	FJ Rapid 5	7.3	de	6.8
			FJ Static	7.8	b	0.4	FJ Static 5	7.2	de	7.6
							FJ Rapid 20	7.7	c	6.0
							FJ Static 20	7.4	cd	7.3
PL	9.3		PL Rapid	9.6	a	1.0	PL Rapid 5	9.2	b	7.6
			PL Static	9.8	a	0.8	PL Static 5	9.2	b	6.9
							PL Rapid 20	9.6	a	8.2
							PL Static 20	9.2	b	6.5
RD	7.6		RD Rapid	7.3	b	0.5	RD Rapid 5	7.1	e	4.0
			RD Static	7.4	b	0.3	RD Static 5	7.1	e	3.7
							RD Rapid 20	7.0	e	4.7
							RD Static 20	7.1	e	5.2
			F value	44.3			F value	93.5		
			P value	< 0.0001			P value	< 0.0001		

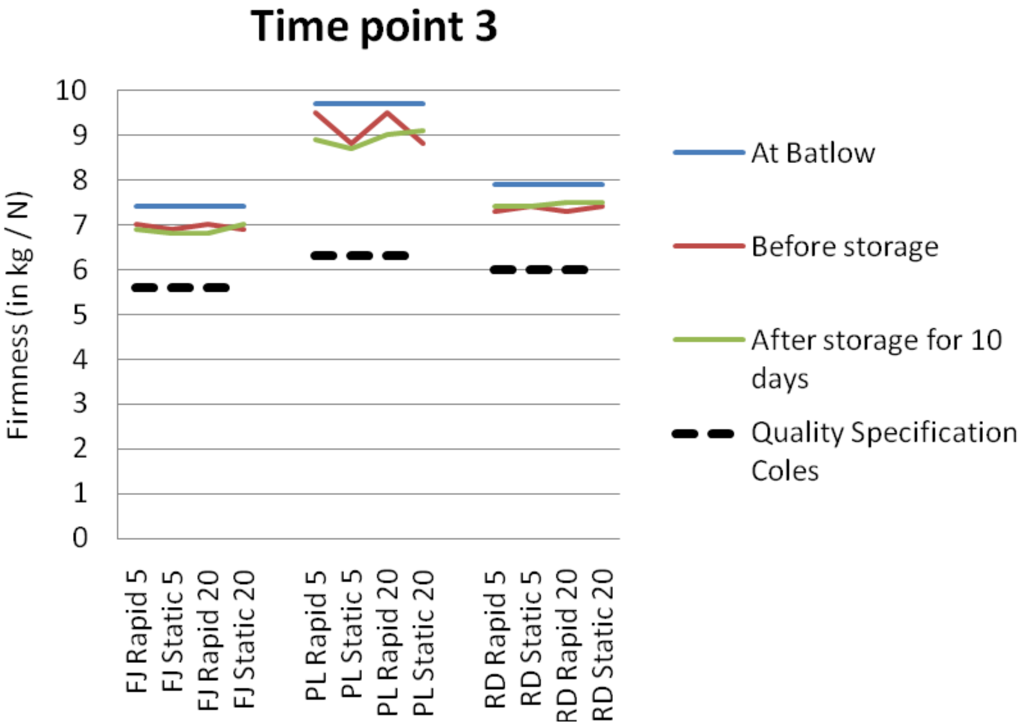
°Brix										
After removal from coolroom (at Batlow)			After rapid or static cooling (upon arrival at CSIRO)				After 10 days of storage at 5° or 20°C (at CSIRO)			
Sample	Mean		Sample	Mean		SD	Sample	Mean		SD
FJ	15.2		FJ Rapid	16.0	b	0.8	FJ Rapid 5	15.6	d	1.2
			FJ Static	16.3	ab	0.7	FJ Static 5	15.7	cd	1.4
							FJ Rapid 20	16.3	ab	0.7
							FJ Static 20	16.3	ab	0.6
PL	16.1		PL Rapid	16.7	a	0.7	PL Rapid 5	16.2	ab	0.7
			PL Static	16.4	ab	0.6	PL Static 5	16.0	bc	0.7
							PL Rapid 20	16.5	a	0.8
							PL Static 20	16.2	ab	0.7
RD	14.1		RD Rapid	13.6	d	0.7	RD Rapid 5	13.6	e	0.7
			RD Static	14.2	c	0.8	RD Static 5	13.2	e	0.8
							RD Rapid 20	13.3	e	0.9
							RD Static 20	13.5	e	0.6
			F value	45.3			F value	74.5		
			P value	<0.0001			P value	< 0.0001		

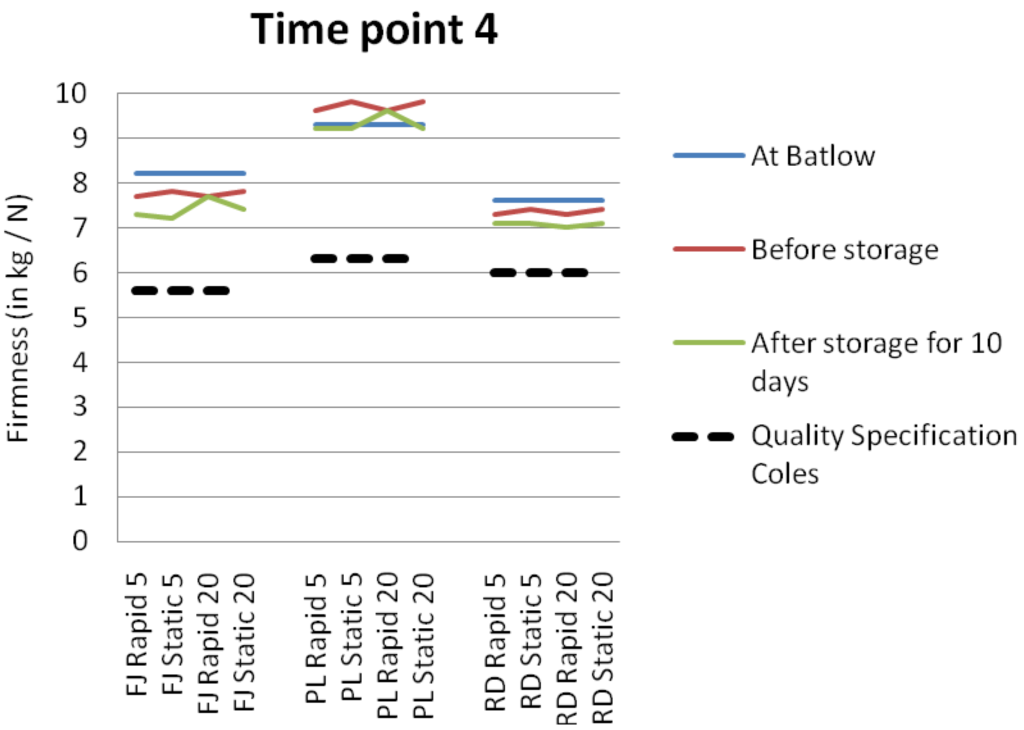
* Samples within the same column grouped by the same letter were not significantly different

Figure 3: Fruit Firmness Pressure measured at Batlow, upon arrival at CSIRO before storage for 10 days, and after 10 days of storage at different temperatures for time points 1 to 4






Time point 3
Firmness (in kg / N)
0
1
2
3
4
5
6
7
8
9
10
FJ Rapid 5
FJ Static 5
FJ Rapid 20
FJ Static 20
PL Rapid 5
PL Static 5
PL Rapid 20
PL Static 20
RD Rapid 5
RD Static 5
RD Rapid 20
RD Static 20
At Batlow
Before storage
After storage for 10 days
Quality Specification Coles


Time point 4
Firmness (in kg / N)
0
1
2
3
4
5
6
7
8
9
10
FJ Rapid 5
FJ Static 5
FJ Rapid 20
FJ Static 20
PL Rapid 5
PL Static 5
PL Rapid 20
PL Static 20
RD Rapid 5
RD Static 5
RD Rapid 20
RD Static 20
At Batlow
Before storage
After storage for 10 days
Quality Specification Coles

3.1.4 Sensory and instrumental quality across four time points

Overall analysis

During each sensory evaluation, apples from previous time points were no longer available, and thereby direct taste comparisons could not be done. By comparing panellist ratings between all time points, it could be verified that panellists were consistent in their scale use, and comparisons across time points can be made.

An overall analysis was conducted to investigate whether there were commonalities across the four time points. This ANOVA analysis took cultivar, time point, storage temperature and cooling method into consideration, as well as their interactions. Results are shown in Table 15. The table indicates for each attribute whether this was significantly different for each of the factors in the analysis, regardless of how large or small the differences were between the samples. Most significant differences were related to differences in cultivar, time point and the interaction between cultivar and time point. Fruit at each time point derived from a different grower. This is the common practice at Batlow Fruit Co-operative, whereby batches are assigned to different cool rooms (i.e. pull dates) on the basis of initial quality measurements after harvest. The results show there were differences between the apples at each of the time points.

Storage temperature effected all texture attributes and some colour, odour and flavour attributes. The storage temperature effect was also different for cultivars and time points for several sensory attributes. Taken over the four time points, cooling method did not affect the sensory attributes or FFP. However, the effect of cooling method was dependent on the time point for several texture attributes; cooling method effected texture at time point 1, but not at the other time points.

Table 15: Statistical significance of the design factors in the study as well as their two-way interactions on sensory and physico-chemical measurements

	Cultivar	Temp	Cooling	Time point	Cultivar by temp	Cooling by time point	Temp by time point	Cultivar by time point
Cream colour	<0.001	<0.001	ns	<0.001	ns	ns	ns	<0.001
Green colour	<0.001	ns	ns	<0.001	ns	ns	.007	<0.001
Odour impact	ns	<0.001	ns	<0.001	.016	ns	.022	ns
Green odour	<0.001	ns	ns	.006	ns	ns	ns	<0.001
Pear odour	.009	<0.001	ns	<0.001	<0.001	ns	<0.001	<0.001
Floral odour	.002	ns	ns	<0.001	ns	ns	.075	ns
Earthy odour	<0.001	.003	ns	<0.001	.001	ns	.001	<0.001
Crispiness	<0.001	<0.001	ns	ns	.010	ns	.059	<0.001
Juiciness	<0.001	<0.001	ns	<0.001	.094	.005	.015	<0.001
Crunchiness	<0.001	<0.001	ns	<0.001	.079	ns	ns	<0.001
Firmness	<0.001	<0.001	ns	<0.001	ns	.004	ns	<0.001
Flouriness	<0.001	<0.001	ns	<0.001	.008	.076	.002	<0.001
Skin toughness	<0.001	ns	ns	<0.001	ns	ns	ns	.001
Flavour impact	<0.001	ns	ns	<0.001	.066	ns	ns	.001
Green flavour	.05	.04	ns	.002	ns	ns	.003	<0.001
Pear flavour	.001	ns	ns	<0.001	ns	ns	<0.001	<0.001

	Cultivar	Temp	Cooling	Time point	Cultivar by temp	Cooling by time point	Temp by time point	Cultivar by time point
Earthy flavour	<0.001	<0.001	ns	<0.001	.001	ns	<0.001	<0.001
Sweet	<0.001	ns	ns	<0.001	ns	ns	ns	<0.001
Bitter	<0.001	ns	ns	<0.001	ns	ns	ns	<0.001
Acidic	<0.001	.001	ns	.001	.03	ns	ns	.002
Sweet aftertaste	<0.001	ns	ns	<0.001	ns	ns	ns	<0.001
Acidic aftertaste	<0.001	.005	ns	<0.001	.002	ns	ns	.004
Astringent afterfeel	<0.001	ns	ns	<0.001	ns	ns	ns	<0.001
FFP	<0.001	.002	ns	<0.001	0.02	0.002	<0.001	<0.001
Brix %	<0.001	0.05	0.007	<0.001	0.03	0.007	0.04	0.001

A Principal Components Analysis (PCA) was carried out using all apples measured at all time points. PCA analysis provides a means to determine the main sensory differences between the samples. The first Principle Component explained 37% of the variance in the data and separated the Fuji and Red Delicious apples from time point 1 from all other samples (see Appendix D). This indicates that these apples were very different from the other apples. In particular the Red Delicious and 20°C Fuji samples were more *floury* than the other apples.

Key sensory attributes and instrumental quality across four time points

The current study focused on the sensory and instrumental characteristics of apples. Sensory descriptive analysis provides insights into objective sensory properties of apples in terms of appearance, odour, flavour and texture. The objective assessments allow for quantification of changes in sensory properties (e.g. *acid taste* or *juiciness*) as a result of the influence of design factors (such as cooling method or storage temperature). However, it does not provide insights in consumer acceptance of apples (*how much consumers like them*) and which sensory attributes are the most important for consumer liking. Such insights require an acceptance study with target consumers, which fell outside of the scope of the current study.

Literature review (see Introduction) found appearance, texture and taste attributes to be important for consumer acceptance. *Flouriness* was disliked by consumers whereas *firmness, crispiness* and *juiciness* were liked. *Sweet* and *acid taste* were also important for consumer liking but their desired intensities may differ. This is also shown in the Eating Quality requirements of the Coles specifications. Whereas all three cultivars are required to have a “crisp” texture, Fuji is required to be “sweet honey like” in taste, Pink Lady “tart with a sweet balance” and Red Delicious is required to have a “mild flavour” (Appendix A).

Results for above mentioned key sensory attributes were further explored. Comparisons between time points were also carried out for physical / chemical measurements. Results are graphically presented in Figure 4. This Figure also includes results from the benchmark study, which are further described in section 3.2.3.

Figure 4 shows that *flouriness* was relatively highest for Red Delicious at time point 1 and, to a lesser extent, time point 4, and for ambient stored Fuji at time point 1. The relatively high *flouriness* of Red Delicious at time point 1 corresponded with a lower FFP, which was below quality specifications of Coles in the case of Red Delicious store ambient for 10 days.

For *juiciness, crispiness* and in-mouth *firmness*, there was no systematic decrease throughout the year, indicating that quality for these texture attributes was well retained. *Sweet* and *acid taste* showed no systematic increase or decrease throughout the year, indicating that the quality of these taste attributes was also well retained throughout the year. An exception was Red Delicious, which continued to slightly decrease in perceived sweetness throughout the year. This trend was followed in Brix % for apples stored chilled but not ambient.

Figure 4 also shows the differences between time points and cultivars that were discussed in previous sections (3.1.2 and 3.1.3). This figure also shows that although differences as a result of storage temperature were significant, in many cases it did not lead to numerically large differences in sensory properties, with the exception of results previously discussed.

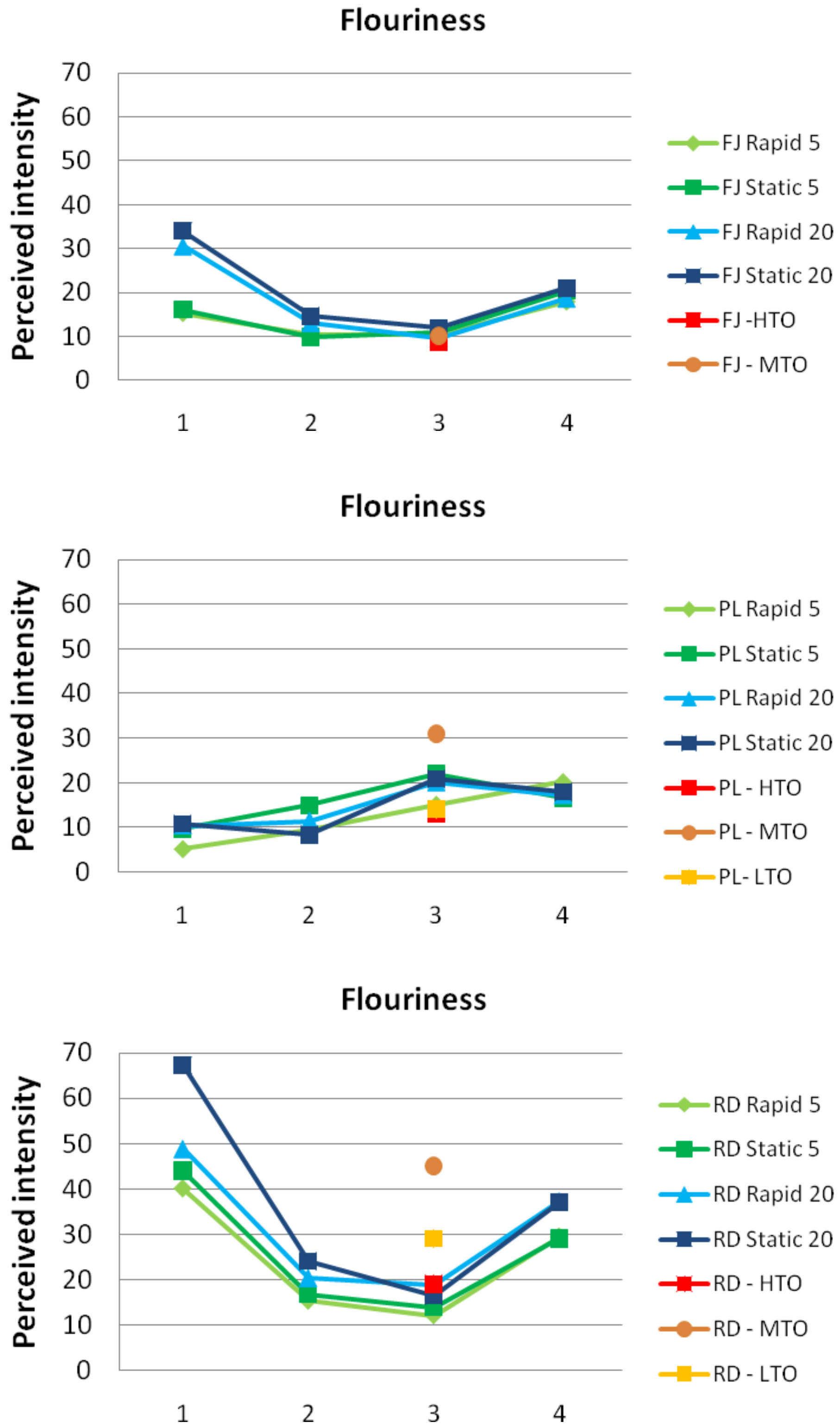
Correlations were calculated between the sensory and instrumental measurements. Fruit Firmness Pressure was significantly and highly positively correlated with in-mouth perceived *firmness* (r = 0.75), but also with other sensory attributes including *crispiness* (r = 0.49), *juiciness* (r = 0.46), *crunchiness* (r = 0.65), *flavour impact* (r = 0.63), *acid taste* (r = 0.82) and *acid aftertaste* (r = 0.77). FFP was negatively correlated with *green colour* (r = - 0.78), *earthy odour* (r = - 0.70), *earthy flavour* (r = - 0.74) and *flouriness* (r = - 0.61).

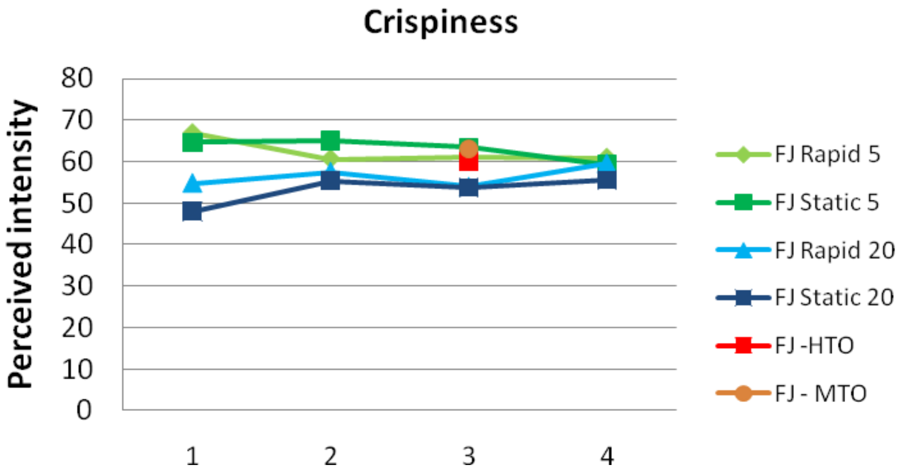
Brix % was significantly correlated with *sweet taste*, although the correlation was only moderately high (r = 0.48). This can also be observed in the graphs relating to these properties in Figure 4, which do not correspond well in Fuji and Red Delicious. The results indicate that there was an overall positive relation between Brix % and *sweet taste*, but that Brix % alone cannot be used to predict the *sweet taste* perceived in-mouth very well. Brix % was correlated with several other sensory attributes also, notably negatively with *green colour* (r = - 0.62)[3], *flouriness* (r= - 0.52) and *bitter taste* (r= - 0.76).

FFP and Brix % were also moderately correlated to each other (r = 0.43), indicating that to some extent higher firmness corresponded with higher Brix %.

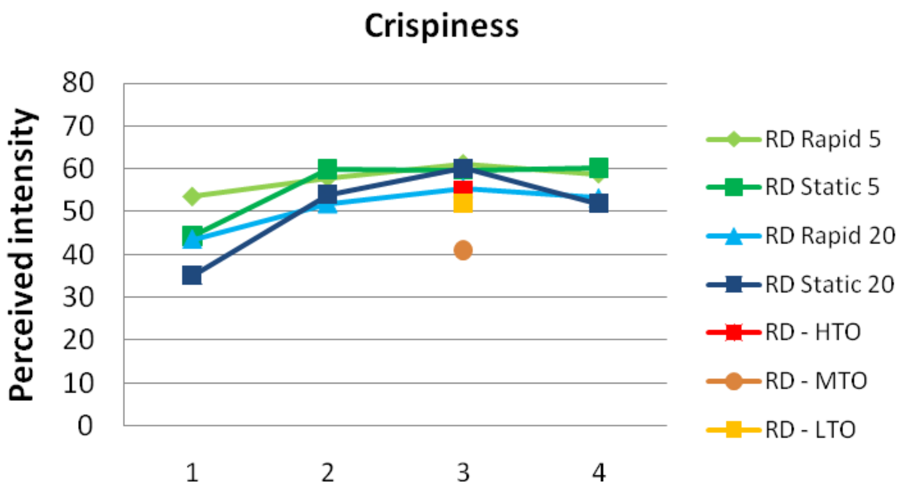
[3] The observed correlation is likely directly related to cultivar, and not cause and effect

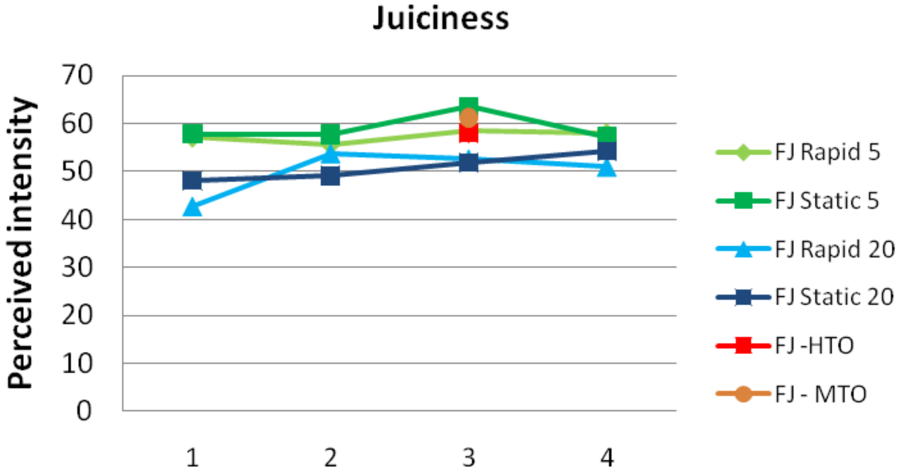
Figure 4: Key sensory attributes and instrumental measurements of Fuji, Pink Lady and Red Delicious apples in the supply chain and the benchmark study



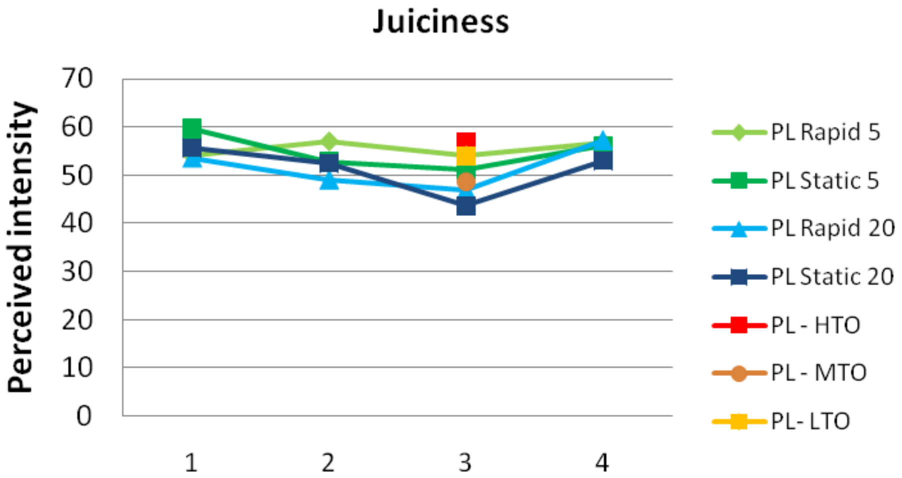

Crispiness
Perceived intensity
80
70
60
50
40
30
20
10
0
1
2
3
4
FJ Rapid 5
FJ Static 5
FJ Rapid 20
FJ Static 20
FJ -HTO
FJ - MTO


Crispiness
Perceived intensity
80
70
60
50
40
30
20
10
0
1
2
3
4
PL Rapid 5
PL Static 5
PL Rapid 20
PL Static 20
PL - HTO
PL - MTO
PL- LTO

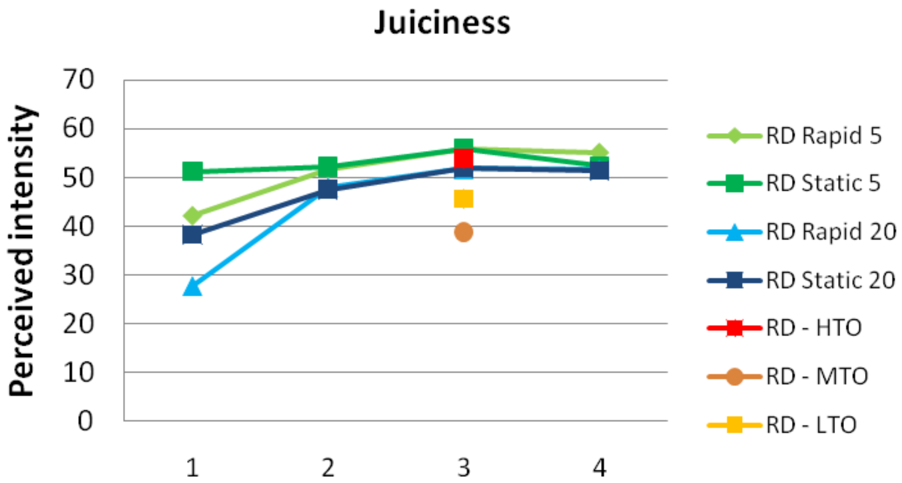

Crispiness
Perceived intensity
80
70
60
50
40
30
20
10
0
1
2
3
4
RD Rapid 5
RD Static 5
RD Rapid 20
RD Static 20
RD - HTO
RD - MTO
RD - LTO



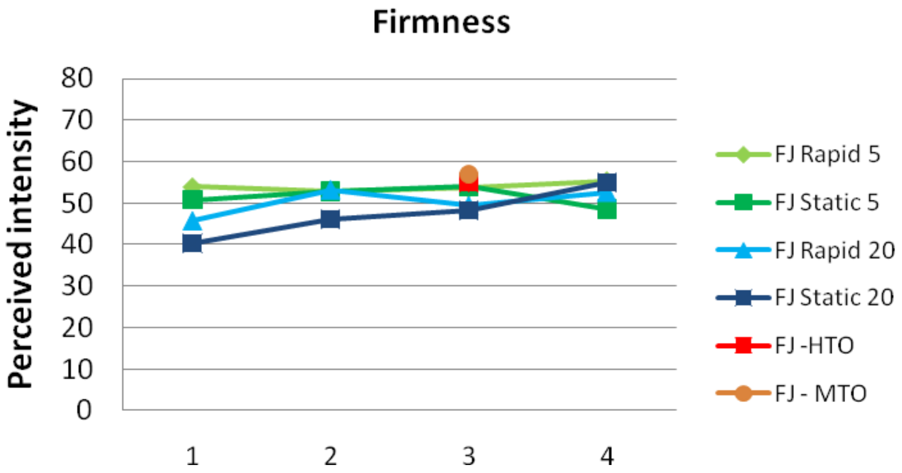
Juiciness
Perceived intensity
70
60
50
40
30
20
10
0
1
2
3
4
FJ Rapid 5
FJ Static 5
FJ Rapid 20
FJ Static 20
FJ -HTO
FJ - MTO

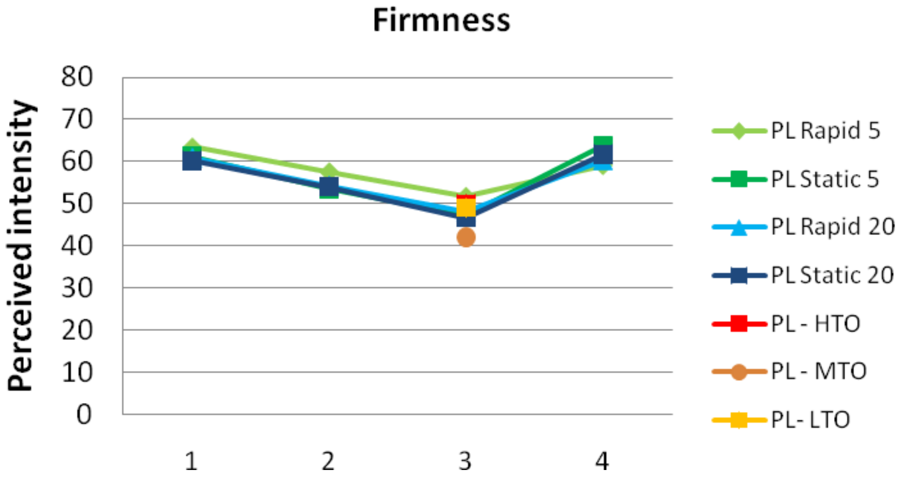


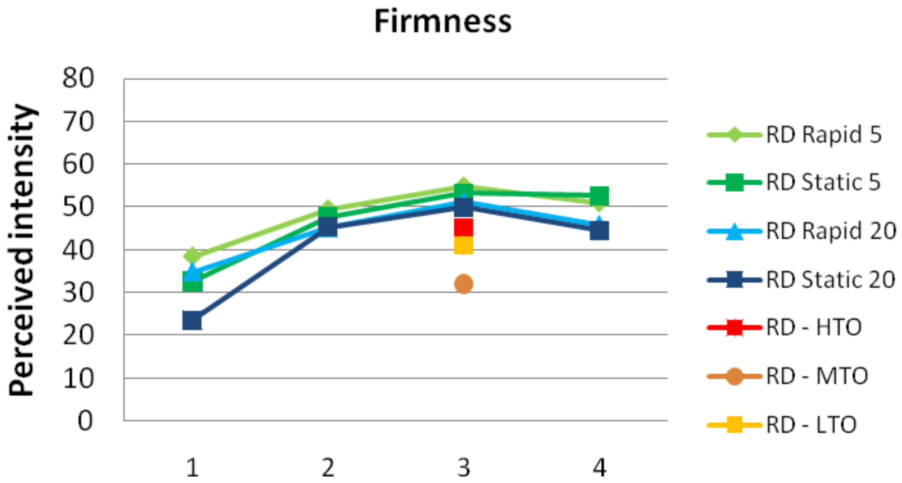
Juiciness
Perceived intensity
70
60
50
40
30
20
10
0
1
2
3
4
PL Rapid 5
PL Static 5
PL Rapid 20
PL Static 20
PL - HTO
PL - MTO
PL- LTO

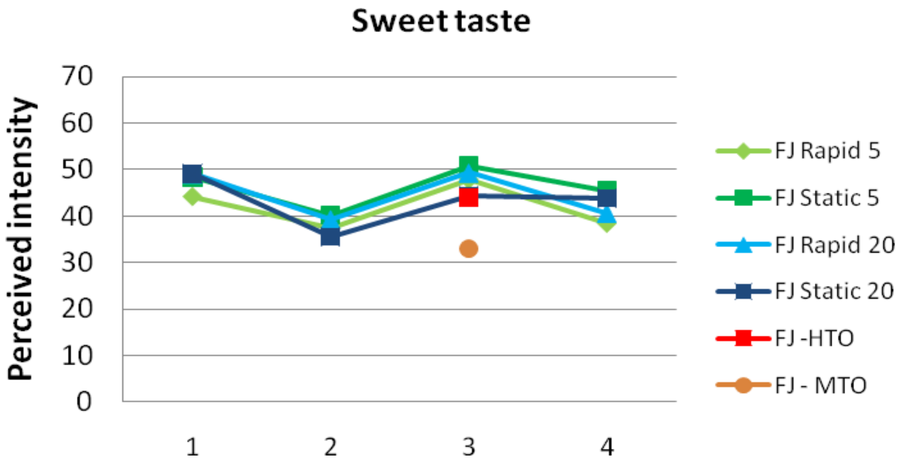


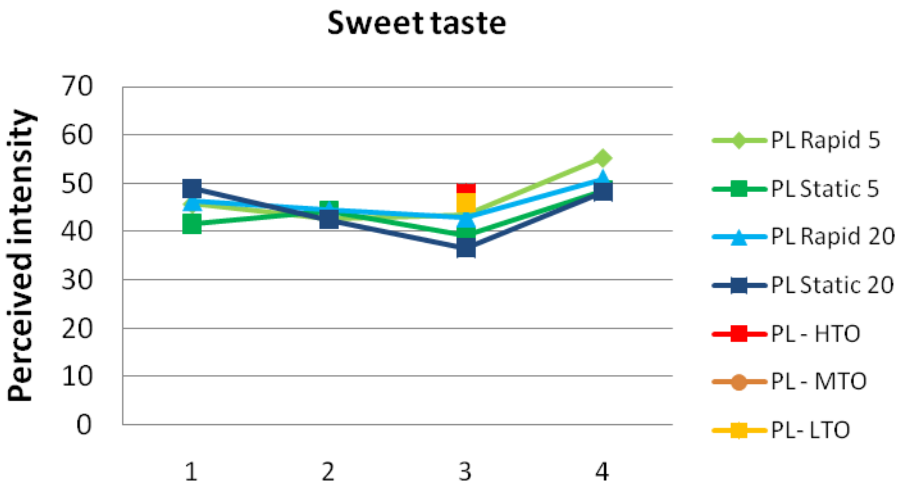
Juiciness
Perceived intensity
70
60
50
40
30
20
10
0
1
2
3
4
RD Rapid 5
RD Static 5
RD Rapid 20
RD Static 20
RD - HTO
RD - MTO
RD - LTO

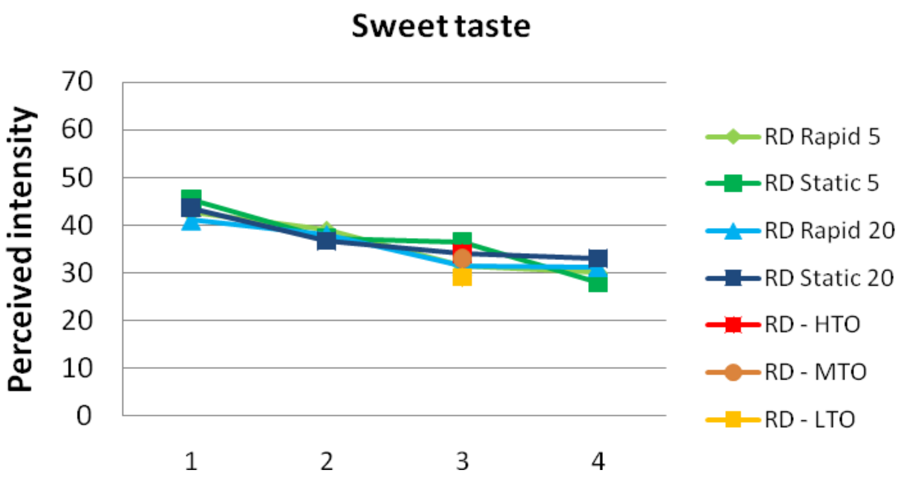

Firmness
Perceived intensity
80
70
60
50
40
30
20
10
0
1
2
3
4
FJ Rapid 5
FJ Static 5
FJ Rapid 20
FJ Static 20
FJ -HTO
FJ - MTO

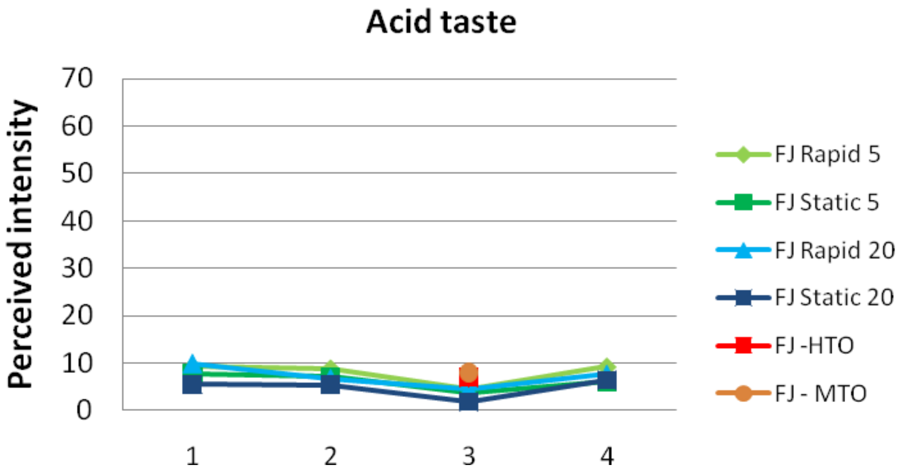

Firmness
Perceived intensity
80
70
60
50
40
30
20
10
0
1
2
3
4
PL Rapid 5
PL Static 5
PL Rapid 20
PL Static 20
PL - HTO
PL - MTO
PL- LTO

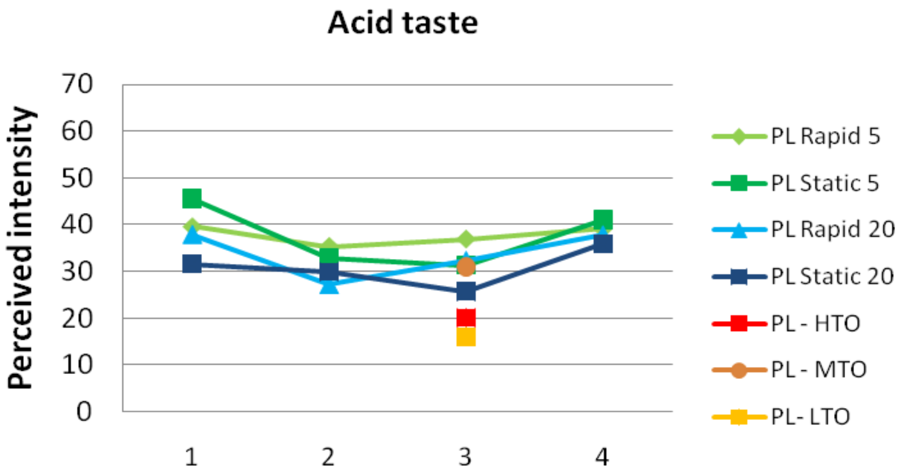

Firmness
Perceived intensity
80
70
60
50
40
30
20
10
0
1
2
3
4
RD Rapid 5
RD Static 5
RD Rapid 20
RD Static 20
RD - HTO
RD - MTO
RD - LTO

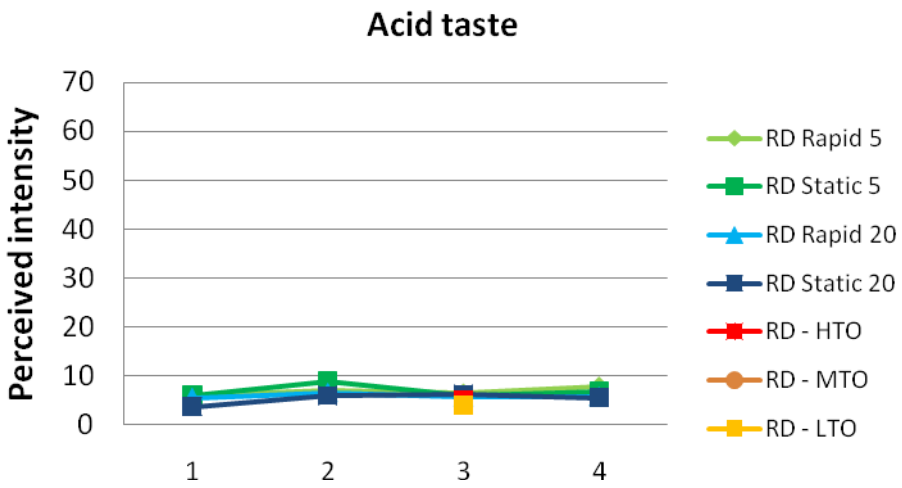

Sweet taste
Perceived intensity
70
60
50
40
30
20
10
0
1
2
3
4
FJ Rapid 5
FJ Static 5
FJ Rapid 20
FJ Static 20
FJ -HTO
FJ - MTO

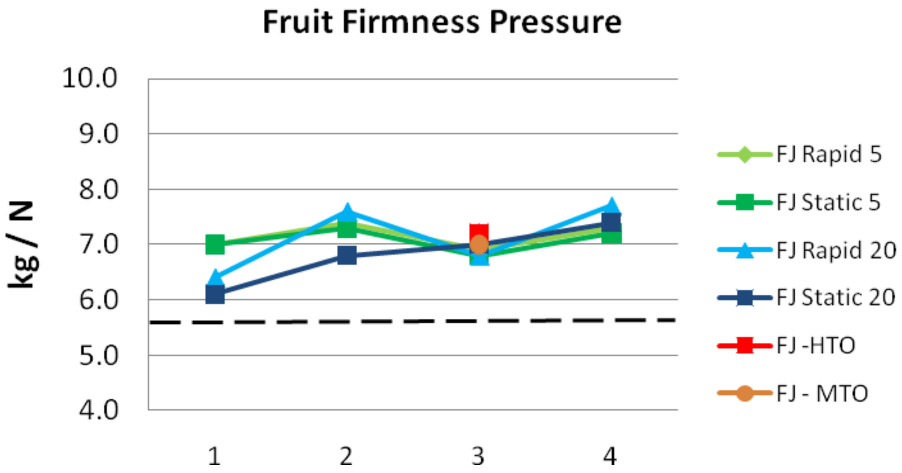

Sweet taste
Perceived intensity
70
60
50
40
30
20
10
0
1
2
3
4
PL Rapid 5
PL Static 5
PL Rapid 20
PL Static 20
PL - HTO
PL - MTO
PL- LTO

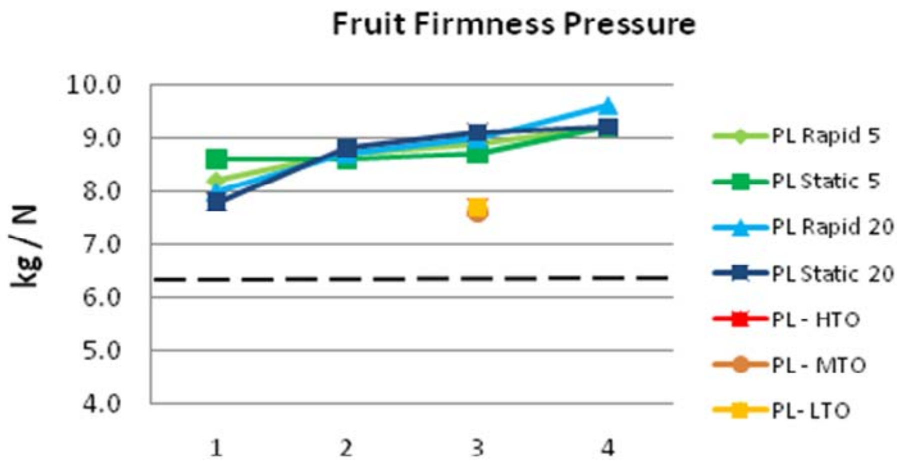

Sweet taste
Perceived intensity
70
60
50
40
30
20
10
0
1
2
3
4
RD Rapid 5
RD Static 5
RD Rapid 20
RD Static 20
RD - HTO
RD - MTO
RD - LTO

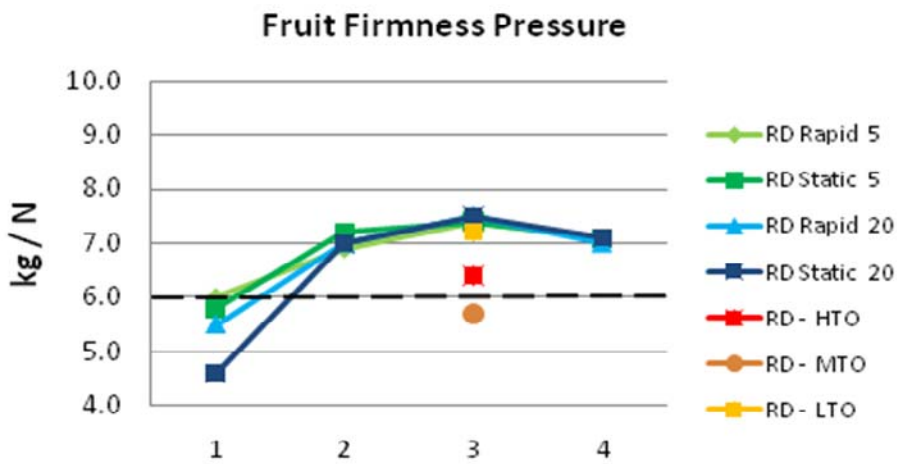

Acid taste
Perceived intensity
70
60
50
40
30
20
10
0
1
2
3
4
FJ Rapid 5
FJ Static 5
FJ Rapid 20
FJ Static 20
FJ -HTO
FJ - MTO


Acid taste
Perceived intensity
70
60
50
40
30
20
10
0
1
2
3
4
PL Rapid 5
PL Static 5
PL Rapid 20
PL Static 20
PL - HTO
PL - MTO
PL- LTO

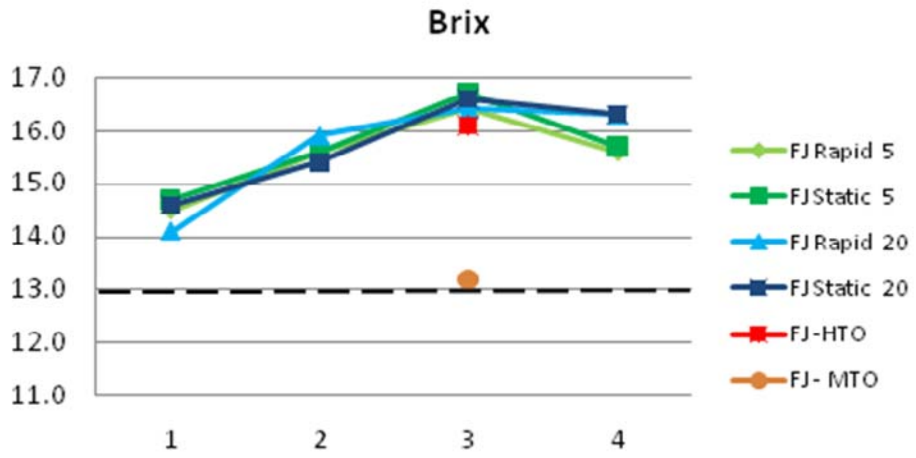

Acid taste
Perceived intensity
70
60
50
40
30
20
10
0
1
2
3
4
RD Rapid 5
RD Static 5
RD Rapid 20
RD Static 20
RD - HTO
RD - MTO
RD - LTO

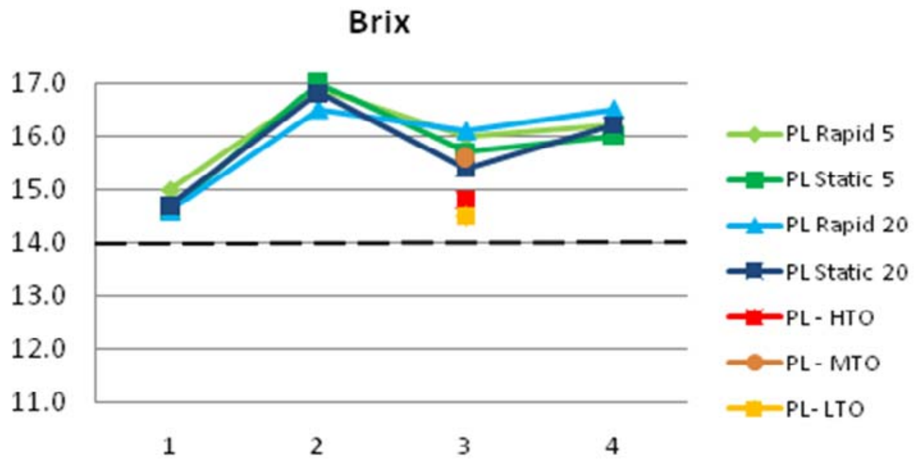


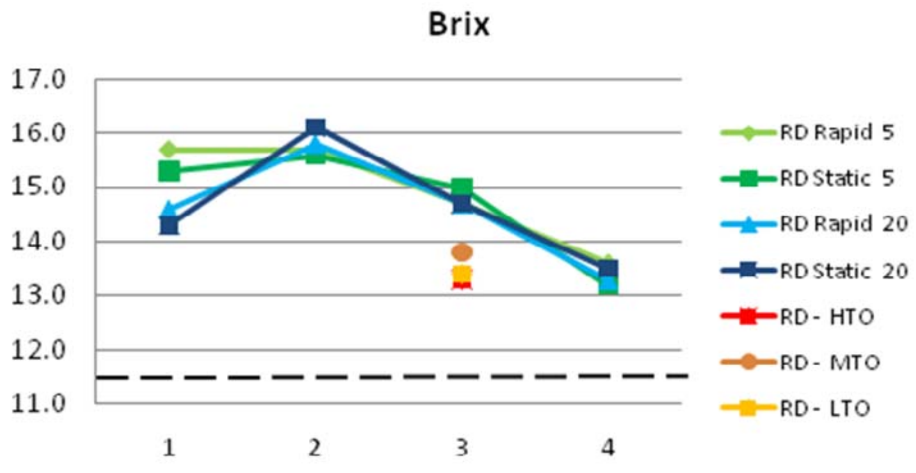




* Dotted lines indicate the quality limits set in the Coles specifications







* Dotted lines indicate the quality limits set in the Coles specifications

3.2 Benchmark study

Delivery data from the Coles DC in the weeks around the benchmark study were used to gain insight into delivery frequencies. These were:

- High turnover store (HTO): deliveries nearly daily
- Medium turnover store (MTO): deliveries 3 to 4 times per week
- Low turnover store (LTO): deliveries 1 to 2 times per week

3.2.1 Sensory assessments

There were significant differences between the eight samples for all sensory attributes (Table 16).

The three apple cultivars were significantly different from each other in all but one sensory attribute (*earthy odour*). Fuji was characterised by a relative high *cream colour, crispness, juiciness, crunchiness* and *firmness* and relatively low *pear odour* and *flouriness.* Pink Lady was characterised by a relatively high *overall flavour impact, pear flavour, acidic taste* and *acidic aftertaste* and a relatively low *green odour* and *flavour.* Red Delicious was characterised by a relatively high *overall odour impact, pear odour, flouriness, skin toughness,* and a relatively low *juiciness, crunchiness, firmness* and *sweet aftertaste*. Red Delicious also had a slight *bitter taste* and *astringent afterfeel.*

There were significant differences between the stores for 12 sensory attributes, with differences in some appearance, odour and flavour attributes and most texture / mouthfeel attributes. Apples from the HTO store were slightly more *crisp, juicy, crunchy* and *firm* and less *floury* than apples from the other stores. However, apples from the MTO store were more *floury* than for the LTO store, with no differences in other texture attributes. Thus, there was no linear relationship between texture characteristics and level of store turnover.

Within cultivars, the following results were obtained:

- The HTO Fuji was significantly more intense in *green colour, pear flavour, sweet taste* and *sweet aftertaste* than the MTO Fuji.
- The MTO Pink Lady was relatively less *juicy, crunchy* and *firm* than Pink Lady apples from the other stores, but more intense in *flouriness, odour impact*, *pear odour, flavour impact* and *acidic taste* and *aftertaste*
- The MTO Red Delicious was less intense in *green flavour* and less *crispy, juicy, crunchy* and *firm* than Red Delicious from the other stores, but more intense in *flouriness* and *pear flavour*. LTO Red Delicious were more *green, floury*, slightly more *bitter* and less intense in *green odour* and *juiciness* than HTO Red Delicious.

Table 16a: Mean intensities from descriptive sensory evaluation of apple colour, odour and texture – Benchmark study

Sample	APPEARANCE		ODOUR					TEXTURE					
	Cream colour	**Green colour**	**Odour impact**	**Green**	**Pear**	**Floral**	**Earthy**	**Crispiness**	**Juici ness**	**Crunchi ness**	**Firmness**	**Flouriness**	**Skin toughness**
FJ - High TO	15.4	23.3	39.6	40.7	13.9	0.6	1.3	60.1	58.0	56.9	55.3	8.7	42.9
FJ – Medium TO	13.3	14.8	42.9	37.9	16.8	0.7	1.2	62.9	61.2	57.5	56.7	10.2	40.9
PL - High TO	12.8	6.1	35.7	23.3	20.1	1.5	5.7	53.7	56.9	51.4	50.2	13.2	36.7
PL - Medium TO	6.7	7.0	47.5	28.3	33.1	2.5	0.8	51.3	48.6	42.7	42.7	30.7	42.2
PL - Low TO	11.2	6.2	35.9	24.0	19.8	1.1	1.8	54.1	54.0	47.6	49.8	14.3	39.9
RD - High TO	9.1	18.9	52.2	41.1	33.1	1.0	2.2	55.1	53.8	46.9	44.7	19.5	59.8
RD - Medium TO	7.3	18.8	55.7	38.5	37.7	3.6	0.7	40.9	38.8	30.4	31.8	45.4	63.1
RD - Low TO	8.8	25.6	48.6	32.2	32.2	3.4	0.2	52.4	45.6	41.0	41.2	29.3	61.7
Overall sample effect													
F value	4.37	27.36	12.65	8.64	12.14	3.48	1.93	6.97	11.03	12.92	11.83	15.61	23.71
P value	<0.01	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<0.01	0.070	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SED	2.7	2.6	3.2	3.9	3.9	1.0	2.2	3.3	3.1	3.4	3.4	3.3	3.8
Effect of design factors in the study (p values)													
Cultivar	<0.01	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.03	ns	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Turnover level	0.04	0.02	<0.01	ns	0.03	ns	0.05	ns	0.01	<0.01	<0.01	< 0.0001	ns
Cultivar* Turnover	ns	<0.01	ns	ns	ns	ns	ns	0.040	<0.01	0.020	0.050	0.020	ns

Table 16b: Mean intensities from descriptive sensory evaluation of apple flavour, aftertaste and afterfeel – Benchmark study

Sample	FLAVOUR				TASTE			AFTERTASTE / AFTERFEEL		
	Flavour Impact	Green	Pear	Earthy	Sweet	Bitter	Acid	Sweet	Acid	Astringent
FJ - High TO	47.3	37.6	34.0	1.9	43.7	1.6	6.9	26.8	4.1	4.8
FJ – Medium TO	48.1	37.9	25.2	3.5	32.6	2.0	8.4	19.0	3.8	4.3
PL - High TO	55.7	25.2	42.7	1.2	47.8	0.2	20.5	29.1	10.0	6.3
PL - Medium TO	61.6	27.0	43.6	3.7	45.8	0.7	30.6	23.5	18.9	9.2
PL - Low TO	54.5	23.8	41.7	2.1	46.0	0.7	16.4	25.0	11.0	6.2
RD - High TO	49.6	39.1	29.1	6.9	34.3	9.7	4.7	17.9	3.4	8.4
RD - Medium TO	47.6	27.7	36.1	9.3	32.7	7.2	3.8	17.7	3.3	9.0
RD - Low TO	47.7	36.6	28.3	7.6	29.5	16.9	4.0	14.4	3.4	9.7

Overall sample effect

F value	5.94	5.86	7.00	3.27	11.76	20.75	26.00	9.72	17.62	2.80
P value	< 0.0001	< 0.0001	< 0.0001	<0.01	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<0.01
SED	3.2	4.0	4.4	3.2	3.7	2.1	3.6	3.1	2.5	2.0

Effect of design factors in the study (p values)

Cultivar	< 0.0001	<0.01	< 0.0001	<0.01	< 0.0001	< 0.0001	< 0.0001	<0.01	< 0.0001	ns
Turnover level	ns	ns	ns	ns	ns	0.00	0.01	ns	ns	ns
Cultivar* Turnover	ns	ns	ns	ns	ns	0.01	0.01	ns	0.04	ns

3.2.2 Instrumental measurements

The following results were obtained:

- The cultivars were significantly different from each other in FFP and Brix % (Table 17). Pink Lady had the highest FFP, followed by Fuji and Red Delicious. Fuji and Pink Lady were higher in Brix % than Red Delicious.
- Within cultivars, there were several significant differences in FFP and Brix %:
- Fuji from the two available stores did not differ in FFP, but the HTO Fuji was higher in Brix % than the MTO Fuji.
- Pink Lady from the three stores did not differ in FFP. In Brix % the MTO Pink Lady was higher than Pink Lady from the other two stores.
- Red Delicious from the three stores significantly differed from each other in FFP, with the LTO apple having the highest, and the MTO apple having the lowest FFP. Red Delicious did not differ from each other in Brix %.
- There was no linear relation between FFP or Brix % and store turnover rate.

Table 17: Fruit Firmness Pressure and Brix % of apples in benchmark study

	FFP			**Brix %**		
Sample	**Mean**		**SD**	**Mean**		**SD**
FJ – High turnover	7.2	b	0.5	16.1	a	1.3
FJ – Medium turnover	7.0	b	0.7	13.2	c	1.1
PL – High turnover	7.7	a	0.7	14.8	b	1.1
PL – Medium turnover	7.6	a	0.7	15.6	a	1.0
PL – Low turnover	7.7	a	0.6	14.5	b	1.1
RD – High turnover	6.4	c	0.7	13.3	c	1.0
RD – Medium turnover	5.7	d	1.1	13.8	c	1.1
RD – Low turnover	7.2	b	1.0	13.4	c	1.5
F value	28.5			25.6		
P value	< 0.0001			< 0.0001		

Samples grouped by the same letter were not significantly different

In conclusion, the results make it clear that apples with a varying range of eating quality are available to the consumer in stores. Differences were found in sensory as well as instrumental characteristics.

3.2.3 Comparison of fruit from benchmark study with supply chain study

The range and variation of sensory and instrumental quality differences observed in apples from the supermarket were compared with those in the supply chain study. If smaller quality differences are found in commercially sold apples than in apples from the conditioned experiment, it can be inferred that the total supply chain conditions were probably better than those simulated in the controlled trial. If larger quality differences are observed than in the controlled experiment, this may be attributed to either larger variation in supply chain conditions or other pre- or postharvest factors not investigated within this study.

Comparison of fruit in the bench mark study (Table 15 and 16) with the supply chain study (Table 9 and 13), showed that the range of intensities encountered in the benchmark study were larger than within the supply chain study for 10 (Fuji) or 11 (Pink Lady and Red Delicious) sensory attributes. These results indicate that larger quality differences were observed in apples from the supermarkets than in the supply chain study. The key sensory attributes and physical-chemical measurements are plotted in Figure 4. This Figure shows that where the supermarket fruit fell outside of the range encountered in the conditioned part of the trial, this was indicative of poorer eating quality. Red Delicious apples from the medium and low turnover store were perceived as more *floury* than encountered in the conditioned fruit from the same time point. Firmness (FFP) of Red Delicious in the medium turnover store was also lower. Fuji from the medium turnover store was perceived as lower in *sweetness* and Brix % than encountered in the conditioned trial. Pink Lady apples from two stores were lower in *acid taste*. Fruit from the high turnover store was similar in key sensory properties to fruit in the supply chain study, although they were lower in FFP or Brix % for some cultivars.

A large difference between the apples in the supply chain study and those obtained from the supermarket shelf is the known storage history. All cultivars from the comparable time point in the supply chain study were CA stored and 1-MCP treated, whereas the storage history of apples obtained from the supermarket shelves was not categorically known. Although all suppliers surveyed used controlled atmosphere storage not all used 1-MCP treatment on their apples. All Fuji apples were 1-MCP treated (including one from Batlow) and sensory quality of these apples, and in particular texture properties, was good in all stores.

3.3 Identification of quality gaps and comparison with current supply chain handling

The sensory and instrumental quality was compared to quality specifications. Quality of fruit before conditioned storage for 10 days met visual and physico-chemical specifications of the retailer and in most cases exceeded this by far. Retailer specifications relate to quality of apples upon arrival at the DC and do not relate to apple quality in stores. Sensory quality cannot be compared to quantitative measures, as no intensities are specified in the Coles specifications.
However, these specifications make clear that decreases in *crispness* and increases in *flouriness* correspond with a decrease in eating quality.

Apples from all three cultivars had a good storage life with the CA / 1-MCP storage conditions and handling practices that Batlow used. A good eating quality was mostly maintained even after storage for 10 days at ambient temperatures.

Visual quality for all apples was good, but some potential gaps in eating quality were identified:

Red Delicious did not maintain their firmness during short term storage directly following harvest (June time point), and in particular with subsequent ambient storage conditions, eating quality was compromised. To a lesser extent, this was observed for Fuji apples directly following harvest, but only when stored ambient. Compared to static cooling, rapid cooling helped maintaining firmness for Red Delicious somewhat and reduced *flouriness*.

Compared to other time points, Red Delicious were also more *floury* at time point 4 than at time points 2 and 3, although they did not differ in other texture properties.

Larger quality differences were found in apples purchased from the supermarket shelves than in the supply chain study. Less than optimal eating quality was found in particular for Red Delicious apples from the low and medium turnover store. As delivery frequencies seem to indicate that turnover was faster than the 10 days of the conditioned trial, it is more likely that the lower eating quality was caused by variables other than prolonged storage at ambient temperatures.

Consumer acceptance research fell outside the scope of this study. Thus, it is not known whether the lower eating quality resulted in unacceptable eating quality to consumers, or was merely suboptimal.

4. DISCUSSION AND CONCLUSIONS

The current study is generally in alignment with previous work that shows that a loss of instrumentally measured firmness was found with higher storage temperatures (Little & Holmes, 2000; Wills et al., 1998), but that this loss also depends on storage conditions (Little & Holmes, 2000; Konpacka & Plocharski, 2004). However, this study also demonstrated that eating quality of apples can generally be maintained well throughout the year. Whereas there was variation in sensory properties and physical and chemical measurements between time points and as a result of storage temperature, eating quality of apples in the supply chain study was largely well maintained even after nine months post harvest. These results showed that apples of good quality can withstand post-DC storage of 10 days at ambient temperatures without compromising eating quality.

To our knowledge, no research relating to the effect of rapid cooling technology on sensory properties of apples has been published. Rapid cooling had a positive effect at time point 1 but had no effect at the other time points. This suggests that rapid cooling may be beneficial in maintaining quality for air stored apples but that its beneficial impact may be mitigated when used in conjunction with CA / 1-MCP.
As batches are assigned to different cool rooms (i.e. pull dates) on the basis of initial quality measurements after harvest, it may also be that more stringent quality specifications were applied to apples to be treated with 1-MCP than for short term air storage, although this did not show in initial physical and chemical measurements.

The scope of this project was limited to one retail store for each apple turnover level. This limitation means that differences found between apples could be attributed to factors other than store turnover rates. Delivery frequencies indicated that turnover in all stores was faster than the 10 days of the controlled study, with the lowest turnover store receiving deliveries once or twice per week. Therefore, unless the first-in first-out policy was not applied, it seems likely that factors other than prolonged storage at ambient temperatures have contributed to the lower eating quality observed at retail. Several factors could be proposed: 1) Storage conditions in the pack house. Different storage conditions may have led to lower quality observed in some apples. Most importantly, it is not categorically known whether apples in the supermarket had been 1-MCP treated; 2) Environmental conditions in the supermarket. Examples are temperature fluctuation experienced diurnally if lighting and air-conditioning cease during store closure. Air flow could also have an impact on apples with the supermarket shelf exposing approximately 80% of the apple surface to the air and apples being continually exposed to variable air flows. Both factors can attribute to water loss and thus sub optimal eating quality. However, none of the apples in our study had any symptoms of skin shrivel, an indicator of extreme water loss; 3) Initial quality. A third variable could be that the quality of commercially sourced fruit was closer to the critical quality limits upon arrival at the DC and thus experienced a smaller margin of error before eating quality decreased. It also cannot be excluded that fruit did not meet firmness specifications at the DC, as instrumental firmness measurements are not conducted on all fruit. More research would be needed to determine if and to what extent these factors affect eating quality of apples in stores.

Our results indicate that initial firmness (FFP) measurements at packing or DC inspection may not necessarily be a reliable indicator of firmness experienced during consumption, particularly for air stored fruit. While Batlow apples exceeded the DC specifications, apples of a quality closer to the DC specifications critical limits may not necessarily provide optimal eating quality following retail and consumer storage.

The physical and chemical measurements carried out correlated with several sensory attributes. Fruit Firmness Pressure was correlated with some texture and other sensory attributes. Brix % showed a moderate correlation with *sweet taste* but was not a reliable guide in predicting all taste and flavour attributes of apples. Similar results have been found by others in relation to instrumentally measured firmness (Harker, Maindonald, Murray, Gunson, Hallett & Walker, 2002; Hoehn, Gasser, Guggenbuhl & Kunsch, 2003; Mehinagic, Royer, Symoneaux, Bertrand & Jourjon, 2004; Konapacka & Plocharski, 2004) and soluble solids (Harker, Marsh, Young, Murray, Gunson, & Walker, 2002; Hoehn et al, 2003). Titratable acidity was also found to have some predictive ability for the *acid taste* (Harker et al, 2002b; Hoehn et al, 2003). However, even studies that combined a range of instrumental measurements could not fully predict the apples' sensory properties. Thus, assessments by human subjects (through trained and/or consumer panels) for apples remain important (Harker et al, 2002a, b). Further work would be required to determine whether sensory properties experienced at the point of consumption could be predicted by sensory assessments of apples at an earlier stage in the supply chain (e.g. at the DC level). If this were the case, it might be worthwhile to include quantitative sensory assessments as part of routine quality control procedures.

Consumer acceptance fell outside the scope of the current study. Insights on key sensory attributes for consumer acceptance were gained from the literature, but desired combinations of sensory attributes and tolerance for decreases in eating quality can only be gained by conducting consumer acceptance research. In combination with descriptive sensory analysis, such research could determine the cultivar-specific key sensory attributes for consumer liking. It could also determine cut-offs for key sensory attributes, below which eating quality is compromised. Bands of acceptance and sensory quality limits could be used in sensory assessments as part of routine quality measurements.

The following conclusions can be drawn from this research:

- Apples from all three cultivars have good storage life with the CA/ 1-MCP combination and the handling practices that Batlow use. However (air stored) Red Delicious did not maintain their firmness during short term storage directly following harvest, and in particular when such storage was suboptimal, this resulted in poorer eating quality. To a lesser extent, similar results were obtained for Fuji apples. Red Delicious were somewhat more *floury* at time point 4 than at time points 2 and 3.

- Rapid cooling was effective to quickly lower the core temperature of apples. Rapid cooling maintained texture properties of Fuji and Red Delicious apples at time point 1 somewhat better than static cooling if fruit experienced suboptimal storage conditions further in the supply chain. In particular it appears to have reduced the development of *flouriness* in Red Delicious. However rapid cooling did not influence eating quality at subsequent time points.

- Storage temperature at ambient or chilled temperature had a significant effect on the majority of sensory and instrumental characteristics. However, the effect was not large for apples that had been CA / 1-MCP stored and resulted in a relatively small decrease in eating quality. This indicates that apples CA / 1-MCP stored were relatively resilient to temperature abuse during retail and consumer handling.

- Some apples purchased in the supermarket had poorer eating quality than apples in the supply chain study. Apples from the high turnover store had good eating quality, in particular regarding texture properties. However, fruit from the medium turnover store was in some cases lower in quality than fruit from the low turnover store.

- Apples in the supply chain study had good visual quality which met or exceeded quality standards. Observed potential gaps in eating quality did not correspond with gaps in visual quality.

5. RECOMMENDATIONS

The following recommendations can be made:

- It is advised to review if the eating quality of Red Delicious apples that have been air stored (and tested in June) can be improved. Options may include CA / 1- MCP treatment, rapid cooling and or tightening of quality specifications.
- Rapid cooling had some advantages in maintaining eating quality of air stored apples at the June time point, particular for Red Delicious apples. However, it did not have such an advantage during long term storage of apples. Investment in rapid cooling equipment for such limited use needs to be balanced against other options to maintain eating quality, such as CA / 1- MCP treatment.
- It is recommended that the apple industry and their supply chain partners further investigate how potential losses in eating quality in supermarkets may occur. With the initial fruit quality and subsequent storage conditions and handling practices of Batlow Co-operative, an eating quality can be obtained that is maintained well even with suboptimal retail storage conditions. A comparison with practices of other pack houses may provide insights that can be further tested. An investigation of the effect of specific retail storage conditions on eating quality of apples, notably air conditioning and lighting, would also be recommended.
- It is recommended to determine eating quality of fruit in a wider range of stores, to determine the extent to which suboptimal eating quality is present to the consumer. As much information about apples and store conditions should be collected simultaneously to enhance the understanding of quality differences. The feasibility of gaining pre-store apple information should be carefully reviewed with stakeholders, as it could significantly enhance understanding.
- It is recommended to investigate consumer acceptance of apples, to determine the loss of eating quality that apples can undergo before acceptance is compromised. It is also recommended that this investigation identify key sensory properties determining acceptance, and to what extent changes to these sensory properties contribute to losses in eating quality below acceptable limits. It may well be that acceptance is cultivar specific, and differs throughout the year, depending on the availability of suitable alternatives.
- Loss of firmness and corresponding eating quality could not always be predicted well on the basis of initial firmness measurements alone. If insights were gained in factors that allow for retention of firmness (such as specific storage conditions) these could be added to the quality specifications in order to ensure good eating quality at consumption.
- It is recommended to assess whether quantitative sensory assessments earlier in a supply chain are better able to predict sensory properties at time of consumption than current instrumental measurements or visual assessments. If this were the case, it may be worthwhile to consider adding sensory assessments to routine quality assurance procedures, for example at the DC level.

6. TECHNOLOGY TRANSFER

Results of this report will be made available to the supply chain partners in this project which will provide them with insights regarding eating quality of apples throughout the year in relation to current supply chain practices.

Dissemination of results to the Apple Industry through industry journals and conferences will be conducted where appropriate. Presentation of results to an international scientific conference is anticipated.

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APPENDIX A COLES SPECIFICATIONS FOR APPLE CULTIVARS

Overview

Product Title	Apple-Fuji--kg--		
Date	18/10/2009	Supercedes	
Business Supplied To	Coles Supermarkets	Crate Weight Minimum	12kg
State	National	APN/PLU	4129, 4131
Country of Origin	Australia		
Pack Life			

Physical Tests

Product File>Specification>Tests

Test	Accept / Pass Criteria
Fresh Produce - A: Variety	Fuji
Fresh Produce - B: Colour	PREMIUM TRAY (6kg)- STANDARD (12kg) Green background with > 60% mild pink/maroon/red blush COMBAT(12kg) Green background with > 50% mild pink/maroon/red blush
Fresh Produce - C: Appearance	Speckled body russet is acceptable
Fresh Produce - D: Eating Quality	Sweet honey like flavour, crisp texture
Fresh Produce - E: Maturity	Bright No dull or greasy skin
Fresh Produce - F: Brix	Brix > 13
Fresh Produce - J: Firmness	Firmness 5.6 kg (11 mm plunger)

Fresh Produce - K: Size	PREMIUM TRAY(6kg): Count 25/28, 30, 32/33. Premium orders should not contain more than two counts per pallet. Premium sizing arrangements must be discussed with the buyer prior to delivery STANDARD Large(12kg): Count 65/66, 60 STANDARD Medium (12kg): Count 82/83, 75/76, 70 COMBAT (12kg): Count 90, 54. Under certain circumstances standard sizing can be used for combat orders Primary Size check: Count reference. Primary Weight check: Box net weight. If the product presents poorly and is not uniform in size the weight reference table should be used. Weight reference table Count Min Max 90 130 145 82 139 156 83 139 155 75 152 175 76 152 167 70 165 181 65 180 196 66 177 196 60 190 224 53 218 250 54 218 250 A tolerance of +/ - 3 grams will apply to 10% of the box for any of the previously mentioned weights *Premium sizing legend* Count 50 (12kg)= 25 (6kg) Count 54/53 (12kg) = 27 (6kg) Count 60 (12kg)= 30 (6kg) Count 65/66 (12kg) = 33/32 (6kg)*
Fresh Produce - L: Shape	Conical/ Squat

Fresh Produce - M: Defects	PREMIUM TRAY 6kg: Minor Defects: Must not exceed three pieces of fruit Major defects: Nil One in every three trays may exhibit a major defect STANDARD (12kg) COMBAT (12kg) Minor Defects: must not exceed 7 pieces of fruit Major defects: Must not exceed 2 pieces of fruit Defects Minor Minor defects are those that do not affect the shelf life of the product. These include: Russet if exhibited on the body of the fruit and is greater than .5cm2 but less than 1cm2 Stalk cavity russet if it exceeds the shoulder of the fruit Skin marks if greater than .5cm2 but less than 1cm2 Superficial bruising which is discoloured at the surface and superficial in depth and is greater than 1cm2 and less than 2cm2 Sunburn which is superficial in depth and discoloured at the surface i.e. yellow/brown Healed hail if greater than .5cm2 but less than 1cm2 may be accumulative Thrip damage if greater than .5cm2 but less than 1cm2 may be accumulative Defects Major Major defects are those, which affect the shelf life and retail performance of the product of the product and include storage disorders and defects such as: Failing pressure/firmness, brix levels or any maturity requirement. Bruising, which is discoloured at the surface and protrudes into the flesh or bruising that is superficial (as previously defined) but greater than 2cm2. Skin marking greater than 1cm2 Unhealed hail damage or healed damage which is greater than 1cm2 Stems punctures which are unhealed or are healed and protrude deep into the flesh All rots and Moulds All Cuts and Splits Water core is acceptable Pest and insect damage Bitter Pit, Scald Greasy in texture
Fresh Produce - N: Presentation	A minimum of 85% fruit stickered with the PLU
Fresh Produce – P: Outer Packaging	Coles B Crate Coles A Crate
Fresh Produce – Q: Treatment	Washed and polished Waxed
Fresh Produce - R: DC Maximum Acceptance	Please refer to Best Before matrix
Fresh Produce - S: Pulp Temperature	1– 6C
Fresh Produce - T: Best Before / Use By	Please refer to Best Before matrix

Packing

Product File>Specification>Packaging

Overview

Product Title	Apple-Pink Lady--kg--		
Date	16/10/2009	Supercedes	
Business Supplied To	Coles Supermarkets	Crate Weight Minimum	12kg
State	Australian Capital Territory, National, New South Wales, Northern Territory, Queensland, South Australia, Tasmania, Victoria, Western Australia	APN/PLU	4130, 5030
Country of Origin	Australia		
Pack Life	Packed on 7 Days		

Physical Tests

Product File>Specification>Tests

Test	Accept / Pass Criteria
Fresh Produce - A: Variety	Pink Lady Apple
Fresh Produce - B: Colour	PREMIUM TRAY (6kg): A green/cream background with a minimum 75% Pink/light Red Blush STANDARD (12kg) COMBAT (12kg) : A green/cream background with a minimum 45% Pink/light Red Blush
Fresh Produce - C: Appearance	Bright
Fresh Produce - D: Eating Quality	Tart apple with a sweet balance. Crisp Flesh.
Fresh Produce - E: Maturity	Crisp Flesh. not dull or greasy skin.
Fresh Produce - F: Brix	Brix > 14
Fresh Produce - J: Firmness	Firmness 6.3 kg (11 mm probe)

Fresh Produce - K: Size	PREMIUM TRAY(6kg): Count 25/28, 30, 32/33. Premium orders should not contain more than two counts per pallet. Premium sizing arrangements must be discussed with the buyer prior to delivery STANDARD Large (12kg): Count 65/66, 60 STANDARD Medium (12kg): Count 82/83, 75/76, 70 COMBAT (12kg): Count 90, 54. Under certain circumstances standard sizing can be used for combat orders Primary Size check: Count reference. Primary Weight check: Box net weight. If the product presents poorly and is not uniform in size the weight reference table should be used. Weight reference table Count Min Max 90 130 145 82 139 156 83 139 155 75 152 175 76 152 167 70 165 181 65 180 196 66 177 195 60 190 224 53 218 250 54 218 250 A tolerance of +/- 3 grams will apply to 10% of the box for any of the previously mentioned weights *Premium sizing legend* Count 50 (12kg)= 25 (6kg) Count 54/53 (12kg) = 27 (6kg) Count 60 (12kg)= 30 (6kg) Count 65/66 (12kg) = 33/32 (6kg)*
Fresh Produce - L: Shape	Conical

Fresh Produce - M: Defects	PREMIUM TRAY 6kg: Minor Defects: Must not exceed three pieces of fruit Major defects: Nil One in every three trays may exhibit a major defect PREMIUM (12kg) - STANDARD (12kg) - COMBAT (12kg) Minor Defects: must not exceed 7 pieces of fruit Major defects: Must not exceed 2 pieces of fruit Defects - Minor Minor defects are those that do not affect the shelf life of the product. These include: Failing colour requirements Russet if exhibited on the body of the fruit and is greater than .5cm2 but less than 1cm2 Stalk cavity russet if it exceeds the shoulder of the fruit Skin marks if greater than .5cm2 but less than 1cm2 Superficial bruising which is discoloured at the surface and superficial in depth and is greater than 1cm2 and less than 2cm2 Sunburn which is superficial in depth and discoloured at the surface i.e. yellow/brown Healed hail if greater than .5cm2 but less than 1cm2 may be accumulative Thrip damage if greater than .5cm2 but less than 1cm2 may be accumulative Defects -Major Major defects are those, which affect the shelf life and retail performance of the product and include storage disorders and defects such as: Failing pressure/firmness, brix levels or any maturity requirement. Bruising, which is discoloured at the surface and protrudes into the flesh or bruising that is superficial (as previously defined) but greater than 2cm2. Skin marking greater than 1cm2 Unhealed hail damage or healed damage which is greater than 1cm2 Stem punctures which are unhealed or are healed and protrude deep into the flesh All rots and Moulds All Cuts and Splits Pest and insect damage Bitter Pit, Scald Greasy in texture
Fresh Produce - N: Presentation	A minimum of 85% fruit stickered with the PLU
Fresh Produce – O: Inner Packaging	Tray insert
Fresh Produce – P: Outer Packaging	Coles B Crate - RPC Coles A Crate - RPC Cardboard accepted
Fresh Produce – Q: Treatment	Washed and polished Waxed
Fresh Produce - S: Pulp Temperature	1 – 6C

Packing

Product File>Specification>Packaging

Description	Value	Details

coles

Overview

Product Title	Apple-Red Delicious --kg--		
Date	18/10/2009	Supercedes	
Business Supplied To	Coles Supermarkets	Crate Weight Minimum	12kg
State	Australian Capital Territory, National, New South Wales, Northern Territory, Queensland, South Australia, Tasmania, Victoria, Western Australia	APN/PLU	4016, 4015
Country of Origin	Australia		
Pack Life	Packed on 7 Days		

Physical Tests

Product File>Specification>Tests

Test	Accept / Pass Criteria
Fresh Produce - A: Variety	Red Delicious Apple
Fresh Produce - B: Colour	PREMIUM TRAY (6kg) Greater than 90% Red, stripy red background allowed STANDARD (12kg) COMBAT (12kg) Greater than 80% Red, stripy background allowed
Fresh Produce - C: Appearance	Bright
Fresh Produce - D: Eating Quality	Crisp, Mild Flavour
Fresh Produce - E: Maturity	Crisp firm flesh, no greasy or wrinkly skin.
Fresh Produce - F: Brix	Brix > 11.5
Fresh Produce - J: Firmness	Firmness 6.0 kg (11 mm probe)

Fresh Produce - K: Size	PREMIUM TRAY(6kg): Count 25/28, 30, 32/33. Premium orders should not contain more than two counts per pallet. Premium sizing arrangements must be discussed with the buyer prior to delivery STANDARD Large12kg): Count 54, 65/66, 60 STANDARD Medium (12kg): Count 82/83, 75/76, 70 COMBAT (12kg): Count 90 Under certain circumstances standard sizing can be used for combat orders Primary Size check: Count reference. Primary Weight check: Box net weight. If the product presents poorly and is not uniform in size the weight reference table should be used. Weight reference table Count Min Max 90 130 145 82 139 156 83 139 156 75 152 175 76 152 167 70 165 181 65 180 196 66 177 196 60 190 224 53 218 250 54 218 250 A tolerance of +/ 3 grams will apply to 10% of the box for any of the previously mentioned weights *Premium sizing legend* Count 50 (12kg)= 25 (6kg) Count 54/53 (12kg) = 27 (6kg) Count 60 (12kg)= 30 (6kg) Count 65/66 (12kg) = 33/32 (6kg)*
Fresh Produce - L: Shape	Elongated

Fresh Produce - M: Defects	PREMIUM TRAY 6kg: Minor Defects: Must not exceed three pieces of fruit Major defects: Nil One in every three trays may exhibit a major defect STANDARD (12kg) COMBAT (12kg) Minor Defects: Must not exceed 7 pieces of fruit Major defects: Must not exceed 2 pieces of fruit Defects Minor Minor defects are those that do not affect the shelf life of the product. These include: Failing colour requirements Russet if exhibited on the body of the fruit and is greater than .5cm2 but less than 1cm2 Stalk cavity russet if it exceeds the shoulder of the fruit Skin marks if greater than .5cm2 but less than 1cm2 Superficial bruising which is discoloured at the surface and superficial in depth and is greater than 1cm2 and less than 2cm2 Sunburn which is superficial in depth and discoloured at the surface i.e. yellow/brown Healed hail if greater than .5cm2 but less than 1cm2 may be accumulative Thrip damage if greater than .5cm2 but less than 1cm2 may be accumulative Defects Major Major defects are those, which affect the shelf life and retail performance of the product of the product and include storage disorders and defects such as: Failing pressure/firmness, brix levels or any maturity requirement. Bruising, which is discoloured at the surface and protrudes into the flesh or bruising that is superficial (as previously defined) but greater than 2cm2. Skin marking greater than 1cm2 Unhealed hail damage or healed damage which is greater than 1cm2 Stems punctures which are unhealed or are healed and protrude deep into the flesh All rots and Moulds All Cuts and Splits Pest and insect damage Bitter Pit, Scald Greasy in texture
Fresh Produce - N: Presentation	A minimum of 85% fruit stickered with the PLU
Fresh Produce – O: Inner Packaging	Tray insert
Fresh Produce – P: Outer Packaging	Coles B Crate - RPC
Fresh Produce – Q: Treatment	Washed and polished Waxed
Fresh Produce - R: DC Maximum Acceptance	Please refer to Best Before Matrix
Fresh Produce - S: Pulp Temperature	1 – 6 C
Fresh Produce - T: Best Before / Use By	Please refer to Best Before Matrix

Packing

Product File>Specification>Packaging

APPENDIX B SIGNIFICANT SENSORY ATTRIBUTES BY DESIGN FACTOR

Table B1: Mean intensities of significant sensory attributes by cultivar – Time point 2

Cultivar	Cream colour	Green colour	Green odour	Pear odour	Earthy odour	Crispiness	Juiciness	Crunchiness	Firmness	Flouriness	Skin toughness
Fuji	19.7	24.3	41.2	10.7	2.4	59.6	54.1	53.1	51.2	11.9	40.2
Pink Lady	9.6	14.3	33.6	16.9	0.4	59.7	52.8	53.7	54.8	10.9	38.7
Red Delicious	19.9	22.3	36.6	15.7	3.6	55.9	49.8	45.9	46.9	19.1	55.1

Cultivar	Flavour Impact	Earthy flavour	Sweet	Bitter	Acidic	Acidic Aftertaste
Fuji	44.4	3.7	38.1	1.8	7.0	3.0
Pink Lady	54.6	0.1	43.5	0.8	31.3	23.3
Red Delicious	45.2	5.0	37.7	5.6	7.1	3.6

Table B2: Mean intensities of significant sensory attributes by storage temperature – Time point 2

	Crispiness	Juiciness	Firmness
5 degrees	60.8	54.5	52.3
20 degrees	56.0	50.0	49.7

Table B3: Mean intensities of significant sensory attributes by cultivar – Time point 3

Cultivar	Cream colour	Green colour	Green odour	Pear odour	Crispiness	Juiciness	Crunchiness	Flouriness	Skin toughness
Fuji	21.2	13.3	37.5	22.8	58.0	56.6	52.9	10.7	41.8
Pink Lady	18.9	6.2	27.8	30.9	51.8	48.9	46.9	19.5	41.5
Red Delicious	10.3	24.4	41.8	19.4	59.1	53.8	52.1	15.3	61.9

Cultivar	Flavour Impact	Green Flavour	Pear Flavour	Earthy Flavour	Sweet	Bitter	Acidic	Sweet Aftertaste	Acidic Aftertaste	Astringent Afterfeel
Fuji	54.2	27.2	39.6	3.1	48.1	1.9	3.6	29.5	1.5	3.3
Pink Lady	57.0	23.2	36.9	4.7	40.5	2.3	31.5	21.2	18.7	9.5
Red Delicious	49.9	40.1	26.9	9.4	33.4	11.9	6.0	16.5	3.8	10.2

Table B4: Mean intensities of significant sensory attributes by storage temperature – Time point 3

temp	Cream colour	Crispiness	Juiciness	Crunchiness	Firmness
5 degrees	14.9	58.9	56.5	53.0	52.4
20 degrees	18.7	53.8	49.8	48.2	48.9

Table B5: Mean intensities of significant sensory attributes by cultivar – Time point 4

Cultivar	Cream colour	Green colour	Odour impact	Green odour	Pear odour	Floral odour	Earthy odour	Crispiness	Juiciness	Crunchiness	Firmness	Flouriness	Skintoughness
Fuji	24.5	18.4	48.1	38.6	15.4	2.4	2.9	58.8	55.1	52.8	52.9	19.5	44.7
Pink Lady	13.2	5.3	47.5	25.3	23.1	4.8	1.1	61.8	55.8	56.8	61.3	17.9	41.4
Red Delicious	9.4	29.1	49.9	33.4	22.7	3.3	4.6	56.0	52.6	45.7	48.5	33.2	64.4

Cultivar	Flavour Impact	Green Flavour	Pear Flavour	Earthy Flavour	Sweet	Bitter	Acidic	Sweet Aftertaste	Acidic Aftertaste	Astringent Afterfeel
Fuji	53.0	28.6	28.0	7.0	42.1	7.1	7.4	28.1	4.2	13.2
Pink Lady	63.4	21.3	31.1	1.3	50.8	1.2	38.4	33.4	25.9	15.9
Red Delicious	48.5	33.7	21.3	9.5	30.6	24.1	6.5	18.6	5.0	27.4

Table B6: Mean intensities of significant sensory attributes by storage temperature – Time point 4

temp	Cream colour	Crunchiness	Earthy Flavour
5 degrees	14.2	53.3	4.5
20 degrees	17.2	50.2	7.3

APPENDIX C INCIDENCE OF QUALITY DEFECTS

Time point 1 (June 2009)

Intact apple							
	After rapid or static cooling (Upon arrival at CSIRO)			After 10 days of storage at 5 or 20 C (at CSIRO)			
Sample	Punctures (%)	Bruises (%)	Decay (%)	Shrivel (%)	Scald (%)	Decay (%)	Bruising (%)
FJ Rapid	6.0	-	-	-	-	-	-
FJ Static	2.0	-	-	-	-	-	-
PL Rapid	3.0	-	2.0	-	-	-	-
PL Static	1.0	-	1.0	-	-	-	-
RD Rapid	1.0	-	-	-	-	-	-
RD Static	2.0	-	-	-	-	-	-

Apple cut open					
	After 10 days of storage at 5 or 20 C (at CSIRO)				
	Core rot (%)	Decay (%)	Browning (%)	Bruising (%)	Other (%)
FJ Rapid 5	-	-	-	-	-
FJ Static 5	-	-	-	-	-
FJ Rapid 20	-	-	-	-	-
FJ Static 20	-	-	-	-	-
PL Rapid 5	-	-	-	-	-
PL Static 5	-	-	-	-	-
PL Rapid 20	-	-	-	-	-
PL Static 20	-	-	-	-	-
RD Rapid 5	-	-	-	-	-
RD Static 5	-	-	-	-	-
RD Rapid 20	-	-	-	-	-
RD Static 20	-	-	-	-	-

Time point 2 (August 2009)

Intact apple								
	After rapid or static cooling (Upon arrival at CSIRO)				After 10 days of storage at 5 or 20 C (at CSIRO)			
Sample	Punctures (%)	Bruises (%)	Decay (%)	Core rot (%)	Shrivel (%)	Scald (%)	Decay (%)	Bruising (%)
FJ Rapid	5.0	3.0	1.0	-	-	-	-	-
FJ Static	3.0	4.0	-	1.0	-	-	-	-
PL Rapid	7.0	12.0	1.0	-	-	-	-	-
PL Static	8.0	10.0	-	-	-	-	-	-
RD Rapid	2.0	3.0		2.0	-	-	-	-
RD Static	2.0	1.0		2.0	-	-	-	-

Apple cut open					
	After 10 days of storage at 5 or 20 C (at CSIRO)				
	Core rot (%)	Decay (%)	Browning (%)	Bruising (%)	Other (%)
FJ Rapid 5	-	-	-	-	-
FJ Static 5	-	-	-	-	-
FJ Rapid 20	3.0	-	-	-	-
FJ Static 20	-	-	-	-	-
PL Rapid 5	-	3.0	-	-	-
PL Static 5	-	-	-	-	-
PL Rapid 20	3.0	-	3.0	-	-
PL Static 20	-	-	-	-	-
RD Rapid 5	17.0	-	-	-	-
RD Static 5	17.0	-	-	-	-
RD Rapid 20	7.0	-	-	-	-
RD Static 20	7.0	-	-	-	-

Time point 3 (November 2009)

Intact apple								
	After rapid or static cooling (Upon arrival at CSIRO)				After 10 days of storage at 5 or 20 C (at CSIRO)			
Sample	Punctures (%)	Bruises (%)	Decay (%)	Core rot (%)	Shrivel (%)	Scald (%)	Decay (%)	Bruising (%)
FJ Rapid	-	-	7.0	-	-	-	-	-
FJ Static	-	-	10.0	-	-	-	-	-
PL Rapid	-	23.0	7.0	-	-	-	-	-
PL Static	-	33.0	10.0	-	-	-	-	-
RD Rapid	-	-	7.0	-	-	-	-	-
RD Static	-	-	3.0	-	-	-	-	-

Apple cut open					
	After 10 days of storage at 5 or 20 C (at CSIRO)				
	Core rot (%)	Decay (%)	Browning (%)	Bruising (%)	Other (%)
FJ Rapid 5	10.0	-	-	-	-
FJ Static 5	13.0	-	-	-	-
FJ Rapid 20	10.0	-	-	-	-
FJ Static 20	23.0	-	-	-	-
PL Rapid 5	-	-	7.0	3.0	-
PL Static 5	-	-	3.0	3.0	-
PL Rapid 20	-	-	13.0	10.0	-
PL Static 20	-	-	20.0	10.0	3.0 (water core)
RD Rapid 5	13.0	-	-	-	-
RD Static 5	13.0	-	-	-	-
RD Rapid 20	37.0	-	-	-	-
RD Static 20	27.0	-	-	-	-

Time point 4 (January 2010)

Intact apple

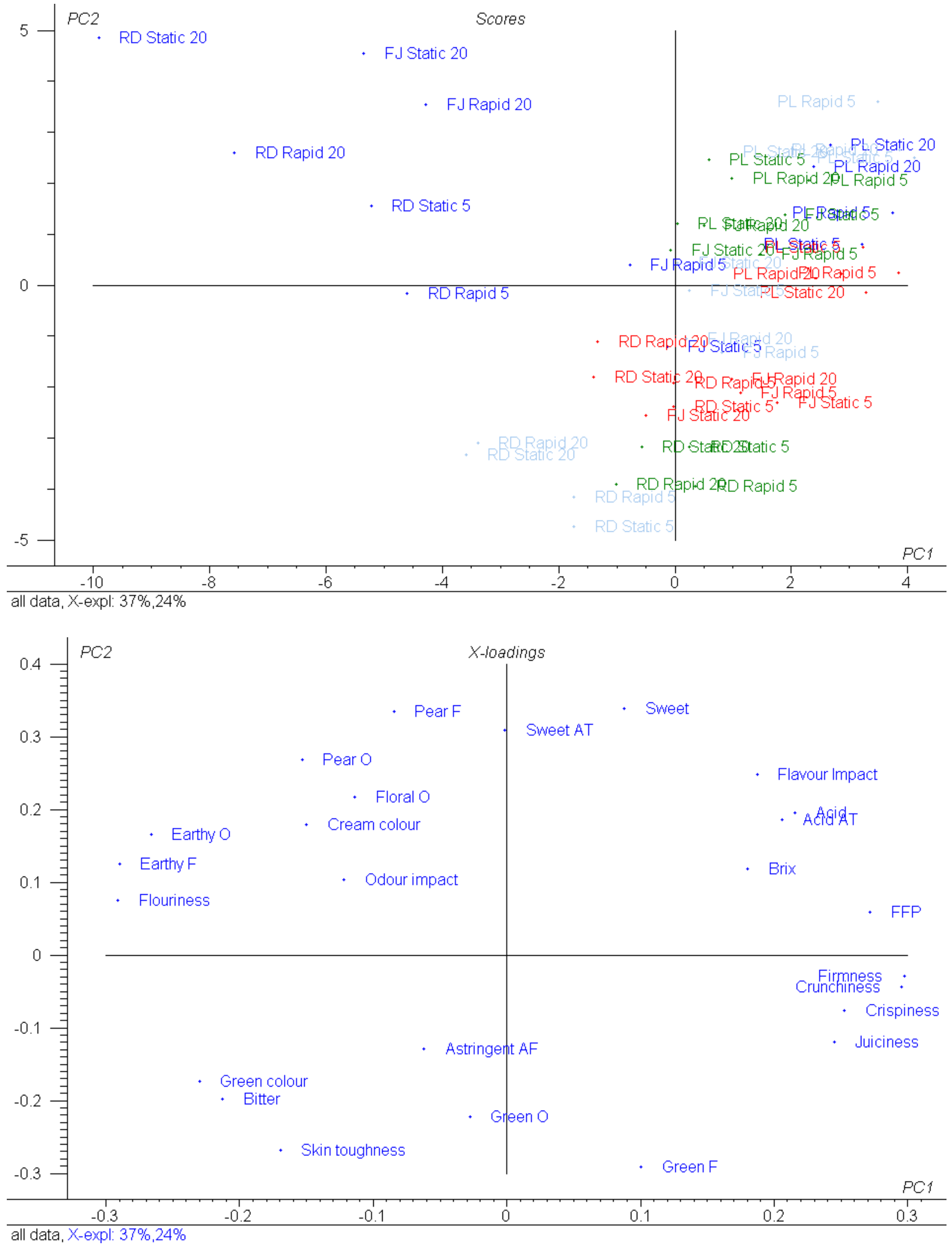
Sample	After rapid or static cooling (Upon arrival at CSIRO) Punctures (%)	Bruises (%)	Decay (%)	Core rot (%)	After 10 days of storage at 5 or 20 C (at CSIRO) Shrivel (%)	Scald (%)	Decay (%)	Bruising (%)
FJ Rapid	3.0	-	-	-	-	-	-	-
FJ Static	3.0	-	-	-	-	-	-	-
PL Rapid	-	10.0	-	-	-	-	-	-
PL Static	-	8.0	-	-	-	-	-	-
RD Rapid	-	3.0	-	-	-	-	-	-
RD Static	-	2.0	-	-	-	-	-	-

Apple cut open

	After 10 days of storage at 5 or 20 C (at CSIRO) Core rot (%)	Decay (%)	Browning (%)	Bruising (%)	Other (%)
FJ Rapid 5	10.0	3.0	-	-	-
FJ Static 5	3.0	-	-	-	-
FJ Rapid 20	13.0	-	-	-	-
FJ Static 20	13.0	-	-	-	-
PL Rapid 5	-	-	-	10.0	-
PL Static 5	-	-	-	3.0	-
PL Rapid 20	-	-	-	7.0	-
PL Static 20	-	-	-	10.0	-
RD Rapid 5	10.0	3.0	-	-	-
RD Static 5	-	-	-	-	-
RD Rapid 20	10.0	-	-	-	-
RD Static 20	7.0	-	-	-	-

APPENDIX D PCA ANALYSIS ACROSS FOUR TIME POINTS

Figure D1: Principal Components Analysis of sensory attributes of apples throughout the four time points (time points are indicated by different colours: dark blue = 1; red = 2; green = 3; light blue = 4)



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