Improvement of Fruit Product Quality and Shelf Life by Changing Temperature Conditions during Transport and Storage

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Abstract

The present study aimed to investigate whether the temperatures usually applied in the supply chain during transport and storage may be too low for optimal sensory and nutritional quality at the time of purchase and after various post-sale periods in a range of fruit. This research began by investigating the effect of temperature on the quality of ten shop bought fruit (peaches, plums, nectarines, strawberries, red grapes, green grapes, mandarins, plum tomatoes, cherry tomatoes and round salad tomatoes) by keeping them at either refrigerator (6°C) or room (22°C) temperature, such as a consumer would after purchase. These fruit were chosen as they were either ASDA's top 10 sold species in 2011, or they had been reported problematic in terms of shelf life (peaches, plums and nectarines). This experiment showed that refrigerator temperatures improved fruit firmness and reduced weight loss, but had a negative effect on the taste of round salad tomatoes, grapes and nectarines, most likely as a symptom of otherwise asymptomatic chilling injury (CI).

The research that followed investigated the effects of keeping round salad tomatoes at a room temperature (RT) of 23°C, ASDA's actual supply chain (SC) temperatures (average 12˚C) or an intermediate temperature of 15˚C (IT) for 7 days. Fruits from each treatment were then either kept at post-sale treatment RT (SCRT/RTRT/ITRT) or kept cold at 5°C (F) (SCF/RTF/ITF), until the end of their shelf life (any visible signs of pathogen infection or more than 15% skin wrinkling). Results showed clear differences in consumer preference after 7 days storage, with consumer scores for SC tomatoes always being significantly lower than those for RT tomatoes in all sensory categories (colour, ripeness, moistness, aroma, sweetness, acidity, flavour, overall opinion), except acidity, firmness and crunchiness. IT treatment delayed the onset of ripening with respect to colour, firmness (instrumental and sensorial) and weight loss compared with RT treatment, and IT treatment improved consumer preferences scores compared with the results of SC tomatoes; however, this was not on par with those from RT treatment. RT treatment also produced the highest lycopene accumulation compared with SC or IT tomatoes during the pre-sale storage phase and refrigeration temperatures during post-sale storage, although IT pre-sale treatment did improve lycopene accumulation compared to SC pre-sale treatment.

After 11 or 15 days in storage, tomatoes from the coldest treatment (SCF) were consistently scored significantly lower in sensory preference than those that had any form of RT storage, showing the detrimental effects of too low temperatures on tomato sensory outcome. Post-sale F treatment also always reduced tomato disease resistance compared with post-sale RT treatment, and those from the coldest treatment SCF always had the lowest shelf life throughout this study, while tomatoes from SCRT or RTRT treatment had the longest shelf life in terms of resistance to disease infection.

The results from this study can be used to update recommendations concerning optimal handling temperatures and highlights the importance of keeping tomatoes out of the refrigerator after purchase. This research demonstrates the need for further exploration into the optimisation of the temperatures used for post-harvest storage of fruit, and suggests that the optimal temperatures for the storage and transport of tomatoes during the supply chain are somewhere between 15°C and 23°C, or above.

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Abbreviations

2.6-dichlorophenolindophenol (DCPIP)

Acetonitrile (ACN)

Chilling injury (CI)

Fresh weight (FW)

Intermediate temperature treatment (IT)

Intermediate temperature-refrigerator treatment (ITF)

Intermediate temperature-room temperature treatment (ITRT)

Kelvin (K)

Refrigeration temperature treatment (F)

Room temperature treatment (RT)

Room temperature-refrigerator treatment (RTF)

Room temperature-room temperature treatment (RTRT)

Supply chain treatment (SC)

Supply chain-refrigerator treatment (SCF)

Supply chain-room temperature treatment (SCRT)

Titratable acidity (TA)

Total soluble solids (TSS)

Trifluoroacetic acid (TFA)

Chapter 1. Introduction

1.1. Fruit

Fruits are vehicles for the production and dispersal of seeds, and are necessary for plant and tree species survival (Munns *et al.,* 2010). They are the edible product of a plant or tree and most develop from an ovary and associated tissue. Most fruits consist of more than 80% water and are made up of between 2-40% carbohydrate, with fruits such as cucumber and tomato being relatively low in carbohydrate contents while bananas, apples and mangoes have higher levels. The dominant sugars found in fruits are sucrose, glucose and fructose and the predominant organic acids are citric and malic acid, although for some fruits such as grapes, tartaric acid is prevalent. Fruits generally contain very low levels of protein and lipids (≥1%), except for avocados and olives which have lipid contents of 20% and 15% respectively (Wills *et al.*, 2007). Fruit are important sources of antioxidants, including Vitamins, phenolic compounds and carotenoids, and the accumulation varies with fruit type, with fruits such as Chinese date (jujube), pomegranate and guava having the highest contents and those such as mangosteen, watermelon and pear having lower levels (Fu *et al.,* 2011).

1.1.1. Fruit Ripening

Ripening is the process by which fruit develop flavour, colour, textural properties and internal qualities, and ripening evolved in fruit for seed consumption by animals and therefore dispersal. Fruit ripening can be climacteric or non-climacteric. Climacteric fruit include species such as tomatoes and avocados, and have an increase in ethylene production associated with an increase in fruit respiration, and can ripen after being harvested. The ripening process of non-climacteric fruit, such as strawberries and apples, is independent of ethylene and associated peaks in respiration, and fruit do not ripen further off the plant (Bapat *et al.*, 2010).

Colour development seen during ripening occurs from the degradation of chlorophyll and photosynthetic apparatus and synthesis of different types of carotenoids and phenolic compounds, such as anthocyanins (Hobson and Davies, 1971). Flavour and aroma increase during ripening which is caused by the production of important volatile compounds and the degradation of bitter compounds such as tannins and flavonoids.

There is also an increase in sugar contents caused by the hydrolysis of polysaccharides, mainly starch, and accumulation of organic acids. Fruits begin to start softening during ripening and reduced firmness is seen and this is caused by changes in the cell wall structure and composition caused by cell wall degrading enzymes (Prasanna *et al.*, 2007).

1.1.2. Fruits and Human Health

Regarding human nutrition, fresh fruits have many health promoting properties and they are a major source of complex carbohydrates required in the human diet, while being low in calorific content. The majority of Vitamin C in the human diet comes from fruit and vegetables (Lee and Kader, 2000) and β-carotene from fruit consumption is for important Vitamin A metabolism (Hickenbottom *et al.*, 2002). Multiple studies have demonstrated positive relationships between fruit and vegetable consumption and human health and the most common associations have been with improved heart health, anti-cancer properties, neuroprotective functioning, anti-inflammatory properties, improved cognition and bone health (Table 1).

Table 1 Summary of the Reported Health Benefits of Fruit. Sources are current reviews, systematic reviews and meta-analyses

Component of Fruit	Reported Health Benefit	Source
Phenolic Compounds	Delay the onset of Alzheimer's Disease	(Rodriguez-Mateos *et al.*, 2014)
	Neuroprotective action	(Rodriguez-Mateos *et al.*, 2014; Babbar *et al.*, 2015)
	Improved cognitive function	(Rodriguez-Mateos *et al.*, 2014)
	Anti-cancer properties	(Mandair *et al.*, 2014; Raiola *et al.*, 2014; Rodriguez-Mateos *et al.*, 2014; Babbar *et al.*, 2015)
	Improved heart health	(Wang *et al.*, 2014; Babbar *et al.*, 2015)
	Anti-inflammatory properties	(Raiola *et al.*, 2014; Babbar *et al.*, 2015)
	Positive association with bone health	(Hardcastle *et al.*, 2011)
	Improves gastrointestinal health	(Quiros-Sauceda *et al.*, 2014)
Carotenoids	Anti-cancer properties	(Mandair *et al.*, 2014; Raiola *et al.*, 2014)
	Control of oxidative stress and inflammation	(Raiola *et al.*, 2014)
	Improved heart health	
	Preserves eye health	
	Prevention of photo-oxidative damage	
	Increasing of DNA resistance to endogenous damage and repair	
	Anti-inflammatory properties	(Kaulmann and Bohn, 2014)
B Vitamins	Energy metabolism action	(Guéant *et al.*, 2013)
	Positive association with bone health	(O'Leary and Samman, 2010; Clarke *et al.*, 2014)
	Improved cognitive function	(O'Leary and Samman, 2010)
Vitamin C	Anticancer properties	(Chambial *et al.*, 2013)
	Involved in the adsorption of Iron	
	Involved in wound healing	
	Improved heart health	(Chambial *et al.*, 2013; Raiola *et al.*, 2014)
	Protection against low density lipoprotein (LDL) oxidation	
	Associated with reduced diabetes	
	Heavy metal toxicity protection	(Chambial *et al.*, 2013)
	Protection against	

	neurodegenerative disorders	
	Prevention of megaloblastic anaemia in pregnant women and involved in regulation of foetal growth	(Raiola *et al.*, 2014)
Vitamin E	Inhibition of lipid peroxidation Improved heart health Anti-cancer properties Decreased risks of type 2 diabetes	(Raiola *et al.*, 2014)
Dietary Fibre	Improved heart health Decreased serum cholesterol and LDL cholesterol concentrations	(Thompkinson *et al.*, 2014)
	Improves gastrointestinal health	(Quiros-Sauceda *et al.*, 2014)
Folate	Prevention of neural tube defects	(Imbard *et al.*, 2013; Meethal *et al.*, 2013; Raiola *et al.*, 2014)
	Anti-cancer properties	(Tio *et al.*, 2014)
	Control of homocysteine metabolism	(Raiola *et al.*, 2014)
Potassium	Enables nerve and muscular functioning	(Gupta and Gupta, 2014)
	Reduces hypertension Positive association with Stroke reduction Improved heart health	(Weaver, 2013; Gupta and Gupta, 2014)

1.1.3. Recommendations for fruit consumption

The advantages of fresh fruits and vegetables have been highlighted by the media over the years, and according to the World Health Organisation (WHO) 1.7 million deaths worldwide are associated with low fruit and vegetable intake (WHO, 2014), although this is most likely a huge underestimation as it difficult to directly ascribe eating habits to mortality. The recommended daily fruit and vegetable intake varies with country. In the UK the National Health Service (NHS) promotes the 'five a day' concept for the daily intake of fruit and vegetables, with each portion being 80g. The NHS provide information online of what counts towards the five a day, how fruit and vegetables can be consumed, and the benefits of fruit and vegetable consumption (NHS, 2013). Five portions of fruit and vegetables are also recommended in Switzerland, however, they suggest that three of these portions should be vegetables and encourage a range of colour to ensure a variety of fruit and vegetables are consumed (FAO, 2015). Denmark have a higher recommendation of six a day or 600 grams, which was derived to increase the consumption of fruit and vegetables in Denmark and is supported by the government, the fruit and vegetable industry and also health organisations, and some of the efforts included an introduction period in 2007 which involved fruit and vegetables provided in schools costing near to one million euros (IFAVA, 2015). The United States (US) take a slightly different approach and recommendations vary with gender and age from 175g for a small child, to 350g for an adult male (USDA, 2012). The WHO recommends a daily minimum of 400g of fruit and vegetables (WHO, 2014), which is in accordance with 5 x 80g portions with no differentiation between quantities and types of fruit and vegetables to consume.

1.1.4. Fruit Consumption Patterns

Consumer expenditure on food and beverages has been seen to rise since 2005 in the UK despite the economic downturn, and in 2013 gross expenditure was at £196 billion. In general, a positive association is seen between household income and fruit and vegetable purchase. In 2012, on average 3.2 portions per person were purchased by the lowest income households, while the highest income households purchased an average of 4.8 portions per day (DEFRA, 2013). The demographic that consume the most fruit and vegetables in the UK are those aged between 55-75 years. Moreover, in 2011 less than a third of the population of adults and only 18% of children consumed the recommended five a day, and 7% of adults and 5% of children included no fruit or vegetables in their diet. (HSCIC, 2012).

In 2008, Slovenia and Italy had the highest consumption of fruit out of the European countries, with over 67% and 79% of men and women respectively consuming fruit on a daily basis, while Bulgaria and Romania consumed the least at less than 41% and 51% of men and women eating fruit on a daily basis (OECD, 2012). Moreover, in the US 38% of the population reported eating fruit and vegetables less than once daily (NCCDPHP, 2013), suggesting that even in developed countries a large proportion of the population are not consuming the recommended daily amounts.

Insufficient consumption of fruit and vegetables is not only occurring in the UK and countries categorised as developed, but is a global problem. In a study involving children aged 13-15 years old from countries India, Indonesia, Burma, Sri Lanka and Thailand it was found that 28% of the children studied were consuming fruit and vegetables less than once a day, with the average portion of fruit consumed daily being 1.3, and children from India and Burma were the most insufficient, while those from Thailand had the highest intake (Peltzer and Pengpid, 2012). Additionally, in a study involving South African adults over 50 years of age, it was found that the mean intake of fruit and vegetables was four portions a day, with 1.8 portions being fruit and 2.2 being vegetables, with the overall prevalence of insufficient fruit and vegetable intake being 69% (Peltzer and Phaswana-Mafuya, 2012)

1.1.5. Uses of Fruit

Generally, the consumer prefers fresh produce as it appears more healthy and wholesome, however, processed fruit is still a way of consumption and fruit is highly versatile and can be frozen, dried, canned, cooked, or consumed in juice form (McGee, 2004), and fruits, such as berries and citrus, are often incorporated into cakes, biscuits, muffins, yoghurts, ice creams and smoothies (Choudhary, 2010).

Fruits are important in many food and drink manufacturing industries. In the alcohol industry fruit are used to make a number of beverages. For example, grapes are important to the wine industry and the most commonly used varieties are *Vitis vinifera* (Jacobson, 2006), and neutral flavoured grapes such as *V. vinifera* variety Trebbiano are common in brandy production (Tsakiris *et al.*, 2014), while apples are used in the production of cider (Kourkoutas *et al.*, 2004). Apples and grapes have also traditionally been used to make vinegars, but tropical fruits such as pineapple and cocoa can also be used (Solieri and Giudici, 2009). Spices made from dried fruits, such as nutmeg or paprika and chilli powder made from pepper fruits (Peter, 2001) are important in everyday cooking, as are oils, such as olive oil made from pressing whole olive fruits (Preedy and Watson, 2010).

Different cultures across the world have developed different uses for fruit, and fruit have many important non-edible roles. Some fruits are used for their decorative qualities such as the attractive berries on holly bushes, prycantha hedges and cotoneaster hedges. Coir, a coconut husk fibre, has been used traditionally to make brushes, mattresses, sacking and insulation in the tropics but can also be used as a medium in potting plants as an alternative to peat (Choudhary, 2010). The opium poppy is used in the drug manufacturing of morphine, an important pain relief drug, which is extracted from the dried liquid produced from unripe seedpods. A number of structurally similar alkaloids, such as codeine which is used as another pain relief drug, and thebaine and codeinone, which are also involved in drug manufacturing such as oxycodone and hydrocodone respectively, are also extracted from the opium poppy (Nagase and Calderon, 2011). Fruit also produce essential oils which are mostly extracted from fruit material by steam distillation in the commercial industry (Van de Braak and Leijten, 1999) and are used in food or cosmetics.

1.1.6. Fruit Production

Fruit is highly popular worldwide and more than twenty five billion tonnes are produced each year. In 2012 India was the largest producer of fresh fruit and contributed near to eight billion tonnes, with over four billion tonnes being tropical fruit. China was the largest producer of citrus fruits in 2012 and supplied over five billion tonnes, while Iran was the largest producer of stone fruit producing 205000 million tonnes of the global production (FAO, 2012).

In many developing countries fruit and vegetable agriculture is crucial to the economy and employs a large proportion of the population (>40%), most noticeably in places such as India and South East Asia where between 40-85% of the population are employed in the agricultural industry, while for countries such as the UK, Germany, Denmark, Norway and the US, less than 3% are employed in agriculture, but for countries such as France, Spain and Italy 3-9% of the population are employed in the industry (FAO, 2013).

1.1.7. Fruit Quality

Consumers have described appearance/condition, taste/flavour and freshness/ripeness as the most important quality aspects of fruit (Tronstad, 1995), and there is demand for both internal and external fruit quality. External quality includes visual appearance, uniformity (size and colour), ripeness and freshness, and plays a key role in the decision to purchase by the consumer. Internal quality refers to fruit flavour, aroma, texture, nutritional value, and absence of pathogens and non-biotic contaminants, and is often related to the overall external quality. Glossiness is also an important fruit quality and enhances the fruit colour and overall appearance. Fruits such as apples, peppers, aubergines, plums and mandarins are often waxed and polished to improve their gloss (Camelo, 2004).

Fruit taste is the combination of sweet and sour, and this is an indication of ripeness and eating quality. The content of soluble solids is a good estimate of total sugar content, and many fruits should have a minimum content of solids before being harvested, such as 6.5% for kiwifruit. Flavour and aroma are key to the overall taste of the fruit, but texture also has an important influence on the eating quality. Firmness and colour are a degree of ripeness, with colour increasing as fruits ripens, while firmness decreases, which in tandem with changes in flavour, the fruit develops its maximum eatable quality, and will continue until the produce becomes over-ripe, which leads to tissue breakdown and decay of the product (Camelo, 2004)

1.1.8. Consumer Satisfaction and Fruit Waste

During the supply chain supermarkets aim for fruit to go from grower to consumer fresh, aesthetically pleasing, disease free and safe to the consumer, while keeping costs and chemical pesticides low (Barkai-Golan, 2001), which can be a challenge for growers, suppliers and supermarkets considering some supply chains last a long time, such as peaches and nectarines grown in Argentina and transported to the UK.

Commercially produced fruit quality has provoked numerous customer complaints and dissatisfaction for over 40 years (Kader et al 1978b; Ratanachinakorn et al 1997; Causse et al 2002) and in the UK 500,000 tonnes of fresh fruit are thrown away a year, costing almost a billion pounds, with the largest contributor being apples and bananas at 180,000 and 83,000 tonnes, costing £300 and £100 million pounds per year respectively (Williams *et al.*, 2009). This is not an issue only found in the UK, and poor fruit quality and shelf life leads to vast quantities of waste causing environmental and economic losses worldwide. North America and Oceania have the largest proportion of waste by the consumer with 17% of the initial fruits or vegetables lost at the consumer level, and Europe has the second highest levels, followed closely by Industrialised Asia, with Sub-Saharan Africa and South and South East Asia having the lowest levels of waste (less than 2%) (Gustavsson *et al.*, 2011). Currently the demand is high for excellent fresh produce quality with a good shelf life, while keeping cost and waste levels low.

1.2. Current Post-harvest Strategies

1.2.1. General Methods to Improve Fruit Quality

There have been many efforts to improve fruit quality over the years. Post-harvest strategies such as 1-methylcyclopropene application, controlled atmosphere storage, modified atmosphere packaging, fruit coatings, UV exposure, ethanol treatment and methyl jasmonate application have been investigated to improve preservation of fresh commodities during the supply chain (Table 2). These strategies have been found to be successful in reducing the respiration rate, colour development, chilling injury (CI), weight loss, and decay and spoilage, while retaining firmness and in some cases have improved taste compared to untreated fruits. However, many strategies are expensive and require specialised equipment, and commonly have been found to reduce nutritional contents such as phenolic compounds and carotenoids. Additionally, coatings used to preserve fruit quality by reducing weight loss through transpiration and providing an antimicrobial barrier, are often made from chitosan, which is unsuitable for vegetarians and vegans.

Table 2 Summary of a Number of Current Post-Harvest Strategies and Their Effects on the Quality of Fresh Fruit

Strategy	Fruit	Effects	Source
Coatings	Tomato	Reduces fungal decay Increases phenolic accumulation Increases protein accumulation Chitosan coating is often made from shell fish and so not suitable for vegetarians and vegans	(Badawy and Rabea, 2009)
	Strawberry	Reduces weight loss Reduces declines in total soluble solids (TSS) for first four days Reduces declines in total phenolic content for first four days Reduces declines in ascorbic acid content Increases overall preference scores Positively effect on reducing cell wall degrading enzymes Increases shelf life by four days After four days untreated fruit had highest levels of TSS and anthocyanins Chitosan is often made from shell fish and so not suitable for vegetarians and vegans	(Gol *et al.*, 2013)
	Plums	Increases glossiness Reduces pathogen incidence Reduces weight loss by up to 3-fold Reduces ethylene production by up to 4-fold Increases firmness Reduces phenolic compounds degradation No effect on flavour Essential oils used in coatings are expensive	(Kim *et al.*, 2013)
Controlled atmosphere storage	Peach	Reduces CI Retains Firmness Retains antioxidant capacity Retains total phenolic levels	(Lee, 2014)

		No effect on ascorbic acid levels No effect on carotenoid levels	
	Mandarin	Reduces weight loss Reduces off-flavours Reduces titratable acidity (TA)	(Rojas-Argudo *et al.*, 2010)
	Grapes	Reduces grey mould incidence No effect on visual quality No effect on sensory quality No effect on soluble solids No effect on TA No effect on weight loss	(Teles *et al.*, 2014)
Ethanol treatment	Grapes	Reduces bacterial numbers Reduces fungal numbers Increases flavour No effect on yeast growth	(Lichter *et al.*, 2002)
	Cherries	Reduces softening Retains visual quality Retains firmness Produces more preferable fruit from sensory perspective Reduces brown rot at 20°C	(Bai *et al.*, 2011)
	Tomato	Reduces decay severity Retains firmness Increases soluble solids Increases total phenolic concentrations No effect on TA No effect on lycopene levels No effect on β-carotene contents Reduces ascorbic acid depletion	(Tzortzakis and Economakis, 2007)
Hyperbaric Treatment	Cherries	Reduces brown rot Reduces mould	(Romanazzi *et al.*, 2008)
	Grapes	Reduces lesion diameter and percentage of grey mould	(Romanazzi *et al.*, 2008)
	Tomatoes	Reduces weight loss Retains colour Retains firmness Retains TSS Retains TA At ten days ripening no differences were seen between untreated and treated fruits in terms of above quality measurements	(Liplap *et al.*, 2013)

	Tomato	Delays tomato softening and pectin solubilisation Reduces decay Reduces lycopene accumulation	(Ortiz *et al.*, 2013)
1-Methylcyclopropene application	Strawberry	Increases phenolic compound accumulation Reduces anthocyanin accumulation Reduces phenylalanine ammonia-lyase activity Reduces total sugar contents No effect on pH No effect on TA	(Villarreal *et al.*, 2010)
	Mandarin	Inhibits leaf senescence in fruits with attached leaves Increases TA Reduces TSS accumulation No effect on respiration rate No effect on colour change No effect on ascorbic acid levels	(Li *et al.*, 2012)
	Mango	Increases TSS contents Reduces CI Reduces ion leakage No effect on pH No effect of TA No effect on firmness No effect on weight loss	(González-Aguilar *et al.*, 2000)
Methyl jasmonate application	Raspberry	Increases flavonol content	(Moreno *et al.*, 2010)
	Peach	Reduces CI Retains TSS levels Retains firmness Did not reduce cell membrane electrolyte leakage when transferred to room temperature Reduces phenolic contents	(Meng *et al.*, 2009)
Modified atmosphere packaging	Peach	Reduces weight loss Reduces respiration rate Increases taste and overall appearance Reduces decay- but only at day 55 Reduces TSS Increases TA	(Akbudak and Eris, 2004)
	Nectarine	Reduces weight loss Reduces respiration rate	(Akbudak and Eris,

		Increases taste and overall appearance Reduces decay Reduces TSS Increases TA	2004)
	Tomato	Retains firmness Reduces colour development Retains TSS Retains TA	(Majidi *et al.*, 2014)(Majidi *et al.*, 2014)
Ozone	Tomato	Reduces weight loss Retains firmness Reduces physiological damage Reduces spoilage No effect on TSS levels No effect on TA levels Reduces lycopene accumulation Reduces ascorbic acid accumulation	(Venta *et al.*, 2010)
	Peach	Did not reduce fungi severity and incidence in inoculated fruit, except for brown rot Increases weight loss	(Palou *et al.*, 2002)
	Grapes	Reduction in grey mould development No effect on weight loss	(Palou *et al.*, 2002)
UV (UV-C)	Strawberry	Reduces red colour development Reduces decay Retains firmness Increases pH levels Reduces total phenolic compound accumulation No effect on TSS No effect on TA	(Pan *et al.*, 2004)
	Tomato	Reduces decay Retains firmness Reduces CI Reduces respiration rate No effect on sugar content Reduces carotenoid accumulation Reduces phenolic acid accumulation	(Vicente *et al.*, 2005)
	Pear	Reduces incidences of mould	(Xu and Du, 2012)

1.2.2. Temperature Management and Chilling Injury

Temperature management is vital to fresh produce quality. Low postharvest temperatures are extensively used within the supply chain aiming to reduce fruit susceptibility to pathogens and the rate of respiration, delaying ripening and preserving quality, therefore increasing shelf life (Kalt et al 1999). However, too low temperatures can have adverse effects on fruit quality. This process is known as chilling injury (CI), and can be seen in tropical and sub-tropical fruits. Postharvest storage of tomatoes below 13°C causes CI, leading to uneven ripening, tomato softening, surface pitting and increased pathogen susceptibility, reduced ripe tomato aroma and flavour and increased off-flavours when compared with tomatoes kept at 20°C (Hobson 1987, Maul et al 2000), and optimal ripening conditions for tomatoes are generally between 18-21°C, (Cantwell, 2013). Citrus fruit are also susceptible to CI, expressed as pitting, staining and necrotic areas in the peel, when exposed to temperatures less than 2-5°C (Sanchez-Ballesta et al 2003), and the current recommended temperatures for mandarin storage are within 5-8°C (Kader and Arpaia, 2002). For peaches, plums and nectarines postharvest storage temperatures of 2.2-7.6°C initiate CI (mealiness, flesh browning, flesh bleeding, flesh translucency, poor flavour) faster than 0°C (Harding and Haller 1934, Smith 1934, Crisosto et al 1999a), and storage/shipping potential of peach, plum and nectarine cultivars is longer at 0°C than 5°C (Crisosto et al 2008), while no information is available about storage above 7.6°C for these fruits. Temperatures of around 0°C are considered the best for commercial strawberry and grape storage because they cause few quality changes, and are an effective way to extend shelf life, however, they lead to fruits of reduced antioxidant and aroma volatile levels (Ayala-Zavala et al 2004).

The temperatures used by supermarkets during transport and storage of fruit are mainly derived from guidelines, and few researchers have had the opportunity to work closely with supermarkets. Table 3 shows the temperatures regimes used by ASDA (one of the major supermarkets in the UK and a subsidiary of Wal-Mart) for a variety of fruit, depending on where they are harvested. However, it must be considered that there will be variation in the temperatures described which will likely be influenced by factors such as seasonal climate within the particular harvest region and efficiency of cooling units/lorries/ships. It is also possible that temperatures used may actually be lower than those described in the effort to maintain shelf life and fruit freshness as it is a challenge for supermarkets to do so considering the vast amounts of produce they handle daily.

CI symptoms are often detected only after the chilled fruit is removed to warmer temperatures, so it is the consumer that experiences poor fruit quality. Moreover, it is likely that many consumers are unaware that fruit are susceptible to CI and often store fresh produce in the refrigerator themselves, aiming to prolong its life, although in many cases this may not be the best option. CI may be a large contributor to the levels of waste in the UK, and globally, both regarding the supply chain and also at home with the consumer.

Table 3 Temperature Regimes used by ASDA for a Number of Fruit

Fruit	Hemisphere of fruit Origin	Temperature (°C)	Duration	Location
Tomato	Northern	14	Overnight	Cool storage
		12	2-3 hours	Lorry
		10	≤3 days	IPL packhouse
		12	Overnight	ASDA depot
		18-25	≤5 days	ASDA store
Tomato	Southern	14	Overnight	Cool storage
		12	4-5 days	Lorry
		10	≤3 days	IPL packhouse
		12	Overnight	ASDA depot
		18-25	≤5 days	ASDA store
Stone Fruit	Northern	2	1 day to 3 weeks	Packhouse
		2	1-2 days	Refrigeration
		2	1-3 days	Lorry
		2	3-14 days	IPL packhouse
		2	Overnight	ASDA depot
		18-25	≤5 days	ASDA Store
Stone Fruit	Southern	2	1 day to 3 weeks	Packhouse
		2	1-2 days	Refrigeration
		2	3-4 weeks	Ship
		2	3-14 days	IPL packhouse
		2	Overnight	ASDA depot
		18-25	≤5 days	ASDA Store
Strawberry	Northern	2-4	1 days	Cool storage
		2-4	3 days	Lorry
		2-4	1-3 days	IPL packhouse
		5-8	≤3 days	ASDA store
Strawberry	Southern	2-4	1 days	Cool storage
		2-4	5 days	Lorry
		2-4	1-3 days	IPL packhouse
		5-8	≤3 days	ASDA store
Mandarin	Northern	6-8	≥10 days	Supply Chain
		18-25	≤ 5 days	ASDA store
Mandarin	Southern	3.5 to 4	≥30 days	Supply chain
		18-25	≤5 days	ASDA store
Grape	Northern	1-6	≥10 days	Cool storage
		18-25	≤ 5 days	ASDA store
Grape	Southern	0.0-0.5	≥30 day	Supply chain
		18-25	≤ 5d	ASDA store

Provided by David Booth and Ian Harrison, International Procurement & Logisitics (IPL) (ASDA)

1.3. Effects of Storage Temperature on Fruit Quality

1.3.1. Shelf life

For fruits that are not consumed or destroyed by pathogens, senescence of the fruit results in seed dispersal following tissue maceration (Hadfield and Bennet, 1997). Senescence is the process that occurs when fruit become overripe and start to degrade as a result of an increase in enzymes that break down fruit organs, such as respiratory enzymes, degrading enzymes and hydrolases (Sacher, 1973). Increased membrane permeability, resulting in ion leakage, is associated with senescence, and changes in membrane lipids, and lipid peroxidation leads to altered membrane properties and result in defects such as ion leakage and cellular breakdown (Marangoni *et al.*, 1996). From a consumer's perspective shelf life is the point that produce is of unacceptable eating quality and the majority of consumers follow 'best before' dates (Kosa *et al.*, 2007), which, in the case of commodities such as fresh fruit and vegetables, are often much earlier than senescence actually occurs.

1.3.1.1. Effect of Temperature on the Shelf Life of Fruit

Limited shelf life, and loss in fruit quality are major problems faced in marketing fresh produce. Bacterial, yeast and mould counts on fruit have been found to increase with storage time (Trinetta *et al.*, 2010). For the majority of fruit, reductions in shelf life are seen with increasing temperatures, either due to pathogen attack or increased shrivelling and reduced overall quality associated with fruit senescence. Table 4 summarises examples of the effects of temperature on fruit shelf life and quality. Tomatoes, unlike most fruit, are a commodity that does not react positively to cold storage in terms of shelf life, due to their high sensitivity to CI. For example, higher levels of decay severity were seen in tomatoes exposed to 2.5°C and 6°C compared with those stored at 12.5°C or 20°C for 27 days (Biswas *et al.*, 2012). Even at warmer temperatures Baldwin et al., (2011) showed tomatoes at stage two ripening (breaker colouration) that were stored at 18°C had more decayed fruits suffering from sour rot than those stored at 13°C at the initiation of their research, although, after 15 days numbers of decayed fruit from storage at 13°C rapidly increased, and it was suggested that this was a symptom of CI. In a different study higher levels of alternaria rot, blue mould rot and cottony leak were found in tomatoes kept at 13°C than at 15°C for up to 70 days (Batu, 2003), and it has previously been reported that alternaria rot and blue mould rot are more prominent when fruit has been deteriorated by chilling injury (Snowdon, 1991).

Table 4 Summary of the Effects of Temperature on Shelf life and Quality of Fruit. Quality is in terms of taste, colour, firmness, weight loss, carotenoids, phenolic compounds, total soluble solids, titratable acidity, pH and Vitamin C

Measure	Outcome in Response to Increasing Temperature	Source
Shelf life	Positive association with decay and shrivelling in peaches	(Fernandez-Trujillo *et al.*, 2000)
	Positive association with decay in grapes	(Ballinger and Nesbitt, 1982)
	Negative association with overall quality and positive association with decay in strawberries	(Ayala-Zavalaa *et al.*, 2004; Ali *et al.*, 2011)
	Negative association with decay severity reduction in tomatoes	(Batu, 2003; Baldwin *et al.*, 2011; Biswas *et al.*, 2012)
Taste	Positive association with taste in tomatoes	(Maul *et al.*, 2000)
	Positive association with taste in mandarin	(Tietel *et al.*, 2012)
	Positive association with taste in peach	(Shinya *et al.*, 2014)
	Positive association with taste in nectarine	(Shinya *et al.*, 2014)
Colour	Positive association with colour development in strawberries	(Wang and Camp, 2000)
	Too low temperature (≤5°C) have negative effect on colour in mandarins	(Tietel *et al.*, 2012)
	Positive association with colour development temperatures in tomatoes	(Biswas *et al.*, 2012)
	Too low temperature (≤6°C) have negative effect on tomatoes	
Firmness	Negative association with firmness in strawberries	(Ali *et al.*, 2011)
	Negative association with firmness in peaches, plums and nectarines	(Crisosto, 2000)

	Negative association with firmness in peaches and nectarines	(Dagar *et al.*, 2011)
	Positive association with firmness in tomatoes	(Farneti *et al.*, 2010)
Weight loss	Positive association with weight loss in strawberries	(Shin *et al.*, 2007)
	Positive association with weight loss in nectarines	(Dagar *et al.*, 2011)
	Positive association with weight loss in tomatoes	(Požrl *et al.*, 2010; Shik and Kang, 2012)
Carotenoids	Positive association with lycopene levels in tomatoes	(Ajlouni *et al.*, 2001; Dumas *et al.*, 2003; Toor and Savage, 2006; Campos *et al.*, 2010)
Phenolic Compounds	Positive association with phenolic compound levels in strawberries	(Ayala-Zavalaa *et al.*, 2004)
	Positive association with phenolic compound levels in tomatoes	(Pinheiro *et al.*, 2013)
	Negative association with anthocyanin levels in red grapes	(Morais *et al.*, 2002)
	Negative association with phenolic contents in tomatoes	(Toor and Savage, 2006)
	No effect on flavonoid contents in tomatoes	
TSS	Negative association with TSS contents in strawberries	(Ayala-Zavalaa *et al.*, 2004)
	Negative association with TSS contents in plums	(Xiaochun, 2010)
	Negative association with TSS contents in grapes	(Zhang *et al.*, 2001)
	Depends on cultivar in tomatoes: 'BHN-189' tomatoes at 10°C had highest TSS contents, while, 'solimnar' tomatoes kept at 5°C had the highest TSS	(Maul *et al.*, 2000)
	No effect on TSS contents in tomatoes	(Farneti *et al.*, 2010)

	No effect on TSS contents in mandarin	(Obenland *et al.*, 2013)
TA	Positive association in TA of tomatoes	(Toor and Savage, 2006)
	Positive association with TA of grapes	(Sun-Duk *et al.*, 2010)
	Negative association with TA of tomatoes	(Farneti *et al.*, 2010)
	No effect on TA of tomatoes	(Maul *et al.*, 2000)
	No effect on TA of mandarin	(Ladaniya, 2011)
pH	Positive association with pH in grapes	(Sun-Duk *et al.*, 2010)
	No association with pH in mandarins	(Hong *et al.*, 2007)
	No association with pH in strawberries	(Nunes *et al.*, 1995; Nunes *et al.*, 2006; Ali *et al.*, 2011)
	No association with pH in plums	(Saini *et al.*, 1996)
	Depends on cultivar in tomatoes: no effect on pH levels in 'solimar' tomatoes, while for 'BHN-189' tomatoes a positive association with pH was found	(Maul *et al.*, 2000)
Vitamin C	Positive association with Vitamin C contents in nectarines	(Aubert *et al.*, 2014)
	Negative association with Vitamin C contents in tomatoes	(Gahler *et al.*, 2003; Žnidarčič *et al.*, 2010)
	Negative association with Vitamin C contents in plums	(Ergun and Jezik, 2011)
	Negative association with Vitamin C contents in mandarins	(Beltrán *et al.*, 2009)
	Negative association with Vitamin C contents in prepared fruit salad (apple, pineapple, grape and orange	(Giacalone *et al.*, 2010)

1.3.2. Taste

Fruit is mainly consumed for its taste and texture, and taste is an important factor that encourages the consumer to buy and consume the same food on a regular basis (Deliza and MacFie, 1996; Ares *et al.*, 2010; Almli *et al.*, 2011). As a result consumer perception greatly influences the agricultural and food industry in terms of the choice of crops and new product development (Thissen *et al.*, 2011). Fruit flavour is affected by the taste and smell of a combination of primary and secondary metabolites including sugars, acids, minerals and volatile compounds (Nikirov *et al.*, 1994; Baldwin *et al.*, 2000; Bood and Zabetakis, 2002; Tietel *et al.*, 2011). Total soluble solids (TSS) have been strongly associated with fruit sweetness (Malundo *et al.*, 1995), while sourness has been highly correlated with titratable acidity (TA) (Malundo *et al.*, 1995; Bucheli *et al.*, 1999; Ladaniya, 2008). The balance between the TSS and TA influence fruit taste, such as the characteristic sweet and sour taste of a tomato (Stevens *et al.*, 1979; Malundo *et al.*, 1995; Bucheli *et al.*, 1999; Tandon *et al.*, 2003), and a positive correlation has been found between TSS/TA ratio and overall consumer acceptability in grapes (Crisosto and Crisosto, 2002; Jayasena and Cameron, 2008), stone fruits (Crisosto and Crisosto, 2005; Iglesias and Echeverria, 2009), mandarins (Keast and Breslin, 2002), strawberries (Awang *et al.*, 1993; Sato *et al.*, 2006), and tomatoes (Baldwin *et al.*, 1998).

1.3.2.1 Analysis of Taste

Fruit taste can be evaluated by methods ranging from simple taste tests to sensory analysis using trained or un-trained panellists. There are four different types of sensory tests. Directional tests involve analysis of the same product, but the product differs in one attribute such as sweetness, while difference tests also use the same product, but differ in an attribute which would in turn effect further sensory perceptions, such as different levels of sugar in a cake recipe would affect the flavour, colour and texture. With triangle tests the participants are required to select the one odd sample out of three, and duo-trio tests involve the participant picking the sample the most similar to the reference (Lawless and Heymann, 2010).

There are different types of scaling that can be used during the questionnaire in sensory analysis. Category scales provide discrete data and require the participant to choose a number or tick a box on a scale of increasing intensity or degree of liking. Line scales are a commonly used alternative to category scales and involve the participant marking a line on an unmarked intensity scale, usually ranging from low to high. The response is recorded as the distance of the mark from one end of the scale (Lawless and Heymann, 2010)

1.3.2.2. Effect of Temperature on Fruit Taste

A number of studies have demonstrated that storage temperatures have an impact on the flavour and aroma of fruit and for the majority of fruit there is a positive association with fruit taste and temperature (Table 4). The research of Maul et al., (2000) is a good example of this in which they showed that trained panellists preferred round salad tomatoes that had been kept at 20°C compared with those from 5°C, 10°C, and 12.5°C storage. Tomatoes stored at 20°C were scored significantly higher in ripe aroma, tomato flavour and sweetness, while being lower in off flavours. Interestingly, these differences were perceived after only two days of storage and persisted until the research was completed at day twelve, with the largest difference being between tomatoes kept at 5˚C and 20°C. However, this research did not have the opportunity to work with a commercial retailer. In another subtropical fruit, mandarin, it has also been shown that warmer temperatures improve flavour, and fruit kept at 8°C had higher likeability compared with those kept at 0°C, 2°C or 4°C, and this was most likely as fruit from 8°C had a higher ratio of TSS/TA and so were perceived as less tart (Tietel *et al.*, 2012).

1.3.3. Colour

Colour is a visual measure of fruit maturity and ripeness, and for many fruit types colour is used to determine when a fruit is ready to be harvested by the producer (Carreño *et al.*, 1995). Visual appearance affects the consumers' decision to purchase fruit as it represents a level of freshness (Campbell *et al.*, 2004), and is an indicator of how the fruit will taste (Usenik *et al.*, 2008), and since most supermarkets do not offer an opportunity for consumers to taste produce before they buy, it is important that fruit is aesthetically pleasing.

1.3.3.1 Measurement of Fruit Colour

Fruit surface colour is often recorded using the Commission Internationale de L'Eclairage (CIE) coordinates L*, a*, and b*, representing lightness, red–green visual opposition and yellow–blue opposition, respectively (CIE, 1976) (Figure 1). This can be done using traditional computer vision systems which uses a camera in conjunction with red, green and blue filters, such as a Chroma Meter. Hyperspectral imaging system is another method that can be used for colour determination and combines spectroscopy and imaging to produce monochromatic images at hundreds of thousands of wavelengths, and so provides spatial information, as well as spectral information for every pixel of the spatial image (Nicolai *et al.*, 2014; Zhang *et al.*, 2014).

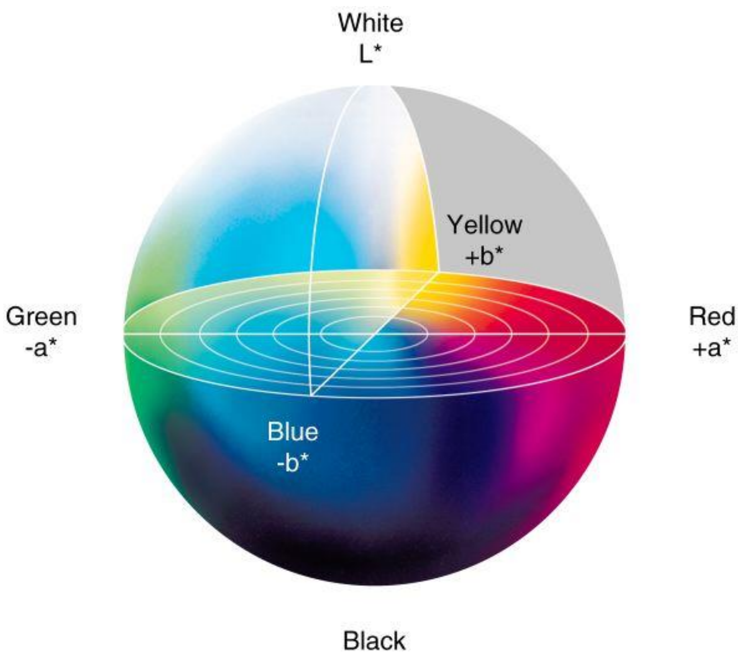

Figure 1 L, a* b* colour space. Colour coordinates used to describe colour, where L represents white or 'lightness', a* represents red–green visual opposition and b * represents the yellow–blue opposition. Image from https://nixsensor.com/how-do-you-measure-color-accuracy/ (NixSensor, 2015)

1.3.3.2. Effect of Temperature on Fruit Colour

In general a decrease in L* value is seen with fruit ripening (Ayala-Zavalaa *et al.*, 2004; Crisosto *et al.*, 2004; Usenik *et al.*, 2008), while a* and b* values change depending on fruit type. For example, during tomato ripening an increase in a* value and decrease in L* and b* is observed (Opara *et al.*, 2012; Carrillo-López and Yahia, 2014), while in mandarins a decrease in L*, a* and b* is seen (Beltrán *et al.*, 2009).

A number of studies have shown that colour development is reduced with low temperature (Table 4), since the rate of respiration is being slowed, and reduced L* value development has been shown in strawberries at lower temperatures (Wang and Camp, 2000). However, too low temperature can have negative effects on fruit colour development, and this has been shown in the research of Tietel et al., (2012) who showed that after four weeks storage at 2°C or 5°C, mandarins had reduced characteristic orange colour and peel became pale yellow as compared with those kept at 8°C where peel colour was deep orange by this time. In another study, red colour development of tomatoes was slowed at 8°C as compared with 20°C for 27 days, while those kept at 2.5°C and 6°C did not development red colour and remained green until they were moved to 20°C. Tomatoes kept at 6°C developed uneven colouration and those from 2.5°C did not develop tomato colour sufficiently (Biswas *et al.*, 2012)

1.3.4. Firmness

Fruit firmness values decrease with ripening (Choi and Huber, 2008; Aday *et al.*, 2011; Dhakal and Baek, 2014), and therefore firmness can also be used as a measurement of shelf life (Ayala-Zavalaa *et al.*, 2004), with very soft fruit being near senescence (Dhakal and Baek, 2014).

Similar to fruit colour, firmness is an important measure of fruit quality by the consumer (Batu, 2004; Chaïb *et al.*, 2007) since in most supermarkets consumers have the opportunity to feel produce before they buy it. The consumer can evaluate the fruit firmness and select fruit that is of their required texture, depending on whether they want the produce ripe and ready, or alternatively choose to ripen at home. Fruits such as stone fruit are highly perishable and once ripe, firmness diminishes rapidly (Crisosto *et al.*, 1993; Taylor *et al.*, 1993; Abdi *et al.*, 1997).

1.3.4.1. Measurement of Fruit Firmness

Since fruit firmness is of high importance to the industry there has been a number of developments in ways to measure firmness, including destructive and non-destructive methods. In terms of destructive measurements, compression tests and puncture tests are the most common methods to measure food texture properties. For compression analysis fruits are usually pressed by a flat plate and the amount of force and distance moved by the plate is calculated, while for penetration a probe rather than a flat plate is used (Chen and Opara, 2013). Non-destructive methods include those such as the mechanical thumb method which measures the deflection of a spring under a load applied to a fruit (Mizrach *et al.*, 1992), while the Sinclair IQTM-Firmness Tester uses the impact of air pressure to measure fruit firmness (Howarth, 2002). Accelerometer methods can also be used which use vibrations created while shaking fruit samples to analyse the firmness (Peleg, 1999), and ultrasonic methods which calculate the energy transmission into fruit to evaluate the overall firmness (Mizrach and Flitsanov, 1999).

1.3.4.2. Effect of Temperature on Fruit Firmness

Temperature is used by supermarkets and consumers to control ripening and therefore fruit firmness. Many studies have shown that lower temperatures maintain fruit firmness compared with ambient temperatures (Table 4), however, low temperatures do not always preserve fruit firmness and it has been shown that refrigeration temperatures of 4°C for 10 days can cause an increase in fruit softening by 23% in fully ripe cocktail tomatoes, cultivar ‘amoroso’ compared with those kept at 15°C (Farneti *et al.*, 2010).

1.3.5. Weight loss

Weight loss is problematic within the fresh produce industry as extreme weight loss can lead to fruit shrivelling, and in worst cases can cause fruit senescence. Fruit weight loss increases with fruit ripening (Tasdelen and Bayindirli, 1998), and with temperature and time (Požrl *et al.*, 2010; Shik and Kang, 2012). As expected weight loss has been positively associated with moisture loss in fruit (Van Dijk *et al.*, 2006; Ngcobo *et al.*, 2013b) mainly caused by transpiration and respiration (Hernandez-Munoz *et al.*, 2006).

The relative humidity of the storage environment and temperature are important in maintaining fresh produce quality (Hung *et al.*, 2011), and weight loss can still be seen in fruit during refrigeration storage, if there is high water vapour pressure deficit caused by low relative humidity as the air cools (Sastry, 1985; Paull, 1999), and humidification of the storage environment can reduce weight loss (Ngcobo *et al.*, 2013a)

1.3.5.1. Effect of Temperature on Fruit Weight Loss

Fruit weight loss is usually expressed as a percentage and is calculated with reference to the initial weight of the fruit at day zero (Parra *et al.*, 2014). A number of studies have shown that fruit weight loss is reduced with lower storage temperatures (Table 4) such as in strawberries, where after three days weight loss was considerably higher in fruit kept at 20°C compared with 10°C and 0.5°C, and weight loss was lowest at 0.5°C (Shin *et al.*, 2007). Similarly, in nectarines weight loss was reduced in fruit kept at 0°C during five weeks storage compared with fruit stored at 5°C (Dagar *et al.*, 2011), and in tomatoes harvested at the middle-red stage and kept at 5°C lower weight loss was observed than those kept at 10°C for 24 days (Požrl *et al.*, 2010). Additionally, tomatoes exposed to three days at 25°C followed by 25 days at 11°C had the greatest weight loss compared with tomatoes stored at temperatures under 11°C (Shik and Kang, 2012)

1.3.6. Total Soluble Solids

TSS are a measurement of fruit sweetness, and are used by the industry as a measure of fruit quality for both processing and fresh markets (Rick, 1974). TSS values indicate the percentage of dissolved solids in fruit juice, and include sugars (mainly glucose, fructose and sucrose), acids, and also in small amounts, phenols, amino acids, soluble pectins, ascorbic acid and minerals (Beaulieu and Saltveit, 1995; Kafkas *et al.*, 2007; Kader, 2008b). High fruit TSS levels are highly desirable in fresh produce due to their contribution to flavour and nutritional value (Jones and Scott, 1993; Kafkas *et al.*, 2007).

1.3.6.1. Measurement of Fruit TSS Contents

TSS can be measured from fruit juice using a handheld refractometer which measures the refractive index, which is a measure of the degree of refraction of a beam of light as it is passed through filtered fruit juice. This is then correlated with TSS as °Brix (Verma and Joshi, 2000).

1.3.6.2. Effect of Temperature on Fruit TSS Contents

TSS levels increase with fruit ripening (Javanmardi and Kubota, 2006; Kader, 2008a; Tao *et al.*, 2012), and once ripe usually begin to decrease with storage time (Ayala-Zavalaa *et al.*, 2004). For fruit suitable for cold storage the rate of decline has been shown to be slower at colder temperatures (Table 4), such as strawberries (Ayala-Zavalaa *et al.*, 2004), plums (Xiaochun, 2010) and grapes (Zhang *et al.*, 2001). However, in tomatoes and mandarins the responses off TSS to temperature has not been found to react accordingly and discrepancies have been seen. Keeping fully ripe tomatoes at 4°C or 15°C for ten days had no effect on the soluble solids, and levels did not change with time (Farneti *et al.*, 2010), and this was also seen for mandarin TSS levels which remained stable during cold storage at 0°C, 4°C and 8°C (Obenland *et al.*, 2013). Conversely, Maul et al., (2000) compared storage of light red ‘BHN-189’ tomatoes at 5°C, 10°C, 12.5°C and 20°C for eight days, and found TSS levels were highest in tomatoes from 10°C, and lowest in fruit from 12.5°C, while in a different cultivar, ‘solimar’, at this time point tomatoes from 5°C had the highest TSS contents compared with tomatoes from the other temperatures, suggesting that TSS values in response to temperature vary with cultivar as well as types of fruit.

1.3.7. Titratable Acidity

1.3.7.1. Measurement of Fruit TA Contents

Titratable acidity (TA) is a measure of the concentration of acid in a solution (Darias-Martına *et al.*, 2003). TA is measured by titrating a known volume of fruit juice with 0.1N sodium hydroxide with an end point of pH 8.2 using phenolphthalein as an indicator. TA can be expressed using the appropriate acid milliequivalent factor as g/100g of citric acid, malic acid or tartaric acid depending on fruit type and the primary acids present (Table 5) (Verma and Joshi, 2000). The levels of organic acids influence both fruit flavour and pH (Thompson et al. 1964).

Table 5 Milliequivalent Factor for Organic Acids in Fruit.

Acid	Milliequivalent Factor	Example of Fruit where acid is prevalent
Citric Acid	0.064	Tomato, Citrus, Berries, Pineapple
Malic Acid	0.067	Peach, plum, Nectarine, Apple, Pear
Tartaric Acid	0.075	Grapes

1.3.7.2. Effect of Temperature on Fruit TA Contents

Research has shown that TA increased in tomatoes with fruit ripening and storage (Dilmaçünal *et al.*, 2011), but begins to decline once fruit become over ripe (Akbudak and Eris, 2004; Žnidarčič *et al.*, 2010; Shik and Kang, 2012), while other researchers have found TA remains stable in peaches and nectarines (Crisosto *et al.*, 2001), mandarins (Obenland *et al.*, 2011) and strawberries (Ali *et al.*, 2011). Several studies have investigated the effects of temperature on TA levels and variations in responses have been found (Table 4). In mandarins, Ladaniya, (2011) found no effect of a range of temperatures (3.5-19.5°C) on TA contents, while in grapes a slight decline in TA has been seen during cold storage (Sun-Duk *et al.*, 2010). TA was found to be more stable in tomatoes held at 4°C rather than 15°C during 10 day storage period (Farneti *et al.*, 2010), while in another study tomatoes held at temperatures ranging from 5-20°C for eight days showed no differences in TA levels (Maul *et al.*, 2000). In addition, the mean TA of tomatoes stored at 7°C was significantly lower than in those exposed to temperatures of 15°C and 25°C for ten days (Toor and Savage, 2006), suggesting variation with cultivars as seen for TSS contents.

1.3.8. pH

1.3.8.1. Measurement of Fruit pH levels

The pH scale ranges from 0-14, with values under 7 being acidic, and those above being basic (Ophardt, 2003), and so pH is measured in conjunction with TA as it is a measure of how acidic or basic a fruit juice/supernatant is. Fruit juice pH is most commonly measured electrochemically using a pH meter which has sensitive electrodes (Andres-Bello *et al.*, 2013).

1.3.8.2. Effect of Temperature of Fruit pH Levels

pH has been seen to increase during postharvest storage of tomatoes (Dilmaçünal *et al.*, 2011), and in peaches and nectarines (Rodríguez *et al.*, 1999; Malakou and Nanos, 2005), while levels in plums have found to be relatively stable over time (Saini *et al.*, 1996; Manganaris *et al.*, 2007; Puerta-Gomez and Cisneros-Zevallos, 2011a). In the majority of fruits, pH levels remain stable at different temperatures (Table 4). However, this was not the case for black grapes where a slight decline was seen in pH during cold storage (Sun-Duk *et al.*, 2010). Additionally, in tomatoes pH values were very similar in cultivar ‘solminar’, while for cultivar ‘BHN-189’, those kept at 5°C for 8 days had the lowest pH, and tomatoes from 20°C had the highest. Similar to TSS and TA contents, it would seem that pH contents in response to temperature vary between and within fruit types.

1.3.9. Carotenoids

Carotenoids are tetraterpenoid pigments synthesised in plant chloroplasts, where they are involved in photosynthesis (Weedon and Moss, 1995; Hirschberg, 2001). Carotenoids are secondary metabolites that are responsible for yellow, orange and red fruit colours (Fraser and Bramley, 2004), which have evolved in fruit to attract insects and animals for seed dispersal, while within the commercial industry are important in consumer purchasing (Kader *et al.*, 1977; Watada and Aulenbach, 1979). Carotenoid content can be linked to instrumental colour measurement (Carrillo-López and Yahia, 2014), for example, in tomatoes the a* values reflects the levels of lycopene, while the *b** value reflects β-carotene synthesis (Arias *et al.*, 2000).

Carotenoids are present in many fruits, including tomatoes, mandarins, peaches, plums and nectarines (Matsumoto *et al.*, 2009). The predominant carotenoids in stone fruit include carotenes α-, β- and γ-carotene, zeaxanthin, lutein, β-cryptoxanthin and violaxanthin (Tomas-Barberan *et al.*, 2001), while β-citraurin, violaxanthin and β-cryptoxanthin and lutein are most prominent in mandarins (Agócs *et al.*, 2007). Lycopene and β-carotene are the two prevalent carotenoids found in tomatoes (Gould, 1974; Friedman, 2013). Lycopene is responsible for the characteristic red colour of tomatoes (Pfander, 1992), which is a significant measurement of fruit quality by the consumer. Carotenoids are also found in strawberries and grapes, but in low amounts (Yano *et al.*, 2005)

1.3.9.1.Measurement of Fruit Carotenoid Contents

Spectroscopic techniques can be used in the identification of carotenoids, including nuclear magnetic resonance (NMR) and mass spectrometry (MS). Chromatography has been commonly used for carotenoid analysis with high-performance liquid chromatography (HPLC) being the most common detection technique used, either with ultra-violet (HPLC-UV) or photodiode array detection (HPLC-PDA), as it allows sensitive isolation and quantification of carotenoids within a relatively short period of time and while keeping precision and sample preservation (Su *et al.*, 2002).

1.3.9.2. Effect of Temperature on Fruit Carotenoid Contents

Carotenoid development is correlated with increased ripening, and fruit from warmer storage conditions have been shown to have high lycopene accumulation, and the optimal temperature for lycopene synthesis has been said to be 16-22°C (Dumas et al., 2003). This has been demonstrated in a number of studies (Table 4). Toor and Savage, (2006) showed that light red tomatoes kept at 15°C and 25°C contained almost 2-fold more lycopene than those kept at 7°C for 10 days. In a different study, increases in lycopene content have also been seen in tomatoes kept at 22°C, while those kept at 4°C showed no changes in their contents during 14 days of storage (Ajlouni et al., 2001). Additionally, Campos et al., (2010) also found lower lycopene concentrations after only 72 hours in red ripe tomatoes stored at 10°C compared with those kept at 24°C. These studies all demonstrate the negative effects of too low temperatures on lycopene accumulation.

1.3.10. Phenolic Compound Content

Phenolic compounds are a group of secondary metabolites that include, flavonoids anthocyanins, flavanols, and phenolic acids (Garcia-Salas *et al.*, 2010). In plants phenolic compounds are involved in stressor responses, such as protection against UV radiation, pathogens and predators, and also as attractants in fruit dispersal (Tsao and McCallum, 2009). Flavonoids are mostly located in the skin of fruit and contribute to important quality aspects such as aroma and colour (Murcia and Martínez-Tome, 2001; D'Introno *et al.*, 2009).

1.3.10.1. Measurements of Phenolic Compound Contents in Fruit

Similar to the analysis of carotenoids, HPLC is a common technique for the measurement of phenolic compounds (da Costa *et al.*, 2000). Alternatively, the Folin-Ciocalteu Assay is a method for analysis of total phenolic contents, and it is rapid and does not require specialised machinery. However, during this assay interfering non-phenolic substances such as sugars and acids, are often included in the total phenolic concentration, so the contents need to be corrected for it to be a true representative of total phenolic accumulation (Prior *et al.*, 2005).

1.3.10.2. Effect of Temperature on the Phenolic Compound Contents of Fruit

Phenolic compounds contents vary with types of fruit and cultivar (Dumas *et al.*, 2003; Moco *et al.*, 2007; Peng *et al.*, 2008; Barros *et al.*, 2012). For example, some of the major phenolic compounds found in grapes are epicatechin, caffeic acid and catechin (Pastrana-bonilla *et al.*, 2003; Rivera-Dominguez *et al.*, 2010), while in tomatoes flavonoids, such as rutin, hydroxycinnamic acid derivatives such as caffeic acid and p-coumaric acid derivatives including chlorogenic acid are the most prevailing (Moco *et al.*, 2007).

Phenolic accumulation in fruit in response to different temperatures varies (Table 4). Phenolic compounds have been found to degrade over time and with higher temperatures, and this was shown in anthocyanin contents from red grapes that had been kept at 24°C, 32°C and 40°C for 14 days, where the higher the temperature, the greater the anthocyanin degradation (Morais et al., 2002). Low storage temperatures have been found to reduce the phenolic compounds in strawberries; fruit kept at 0°C had constant levels of phenolic compounds during the 13 day study, compared with the contents of those kept at 10°C and 5°C which increased with time (Ayala-Zavalaa et al., 2004), and in light red tomatoes kept at 7°C, 15°C and 25°C for 10 days, only small changes in total soluble flavonoid contents were seen, and the soluble phenolic content increased by a small amount during the initial 8 days of storage in tomatoes kept at 7°C and 15 °C, while tomatoes kept at 25°C showed a decline in phenolic contents. On average tomatoes stored at 25°C had lower phenolic and flavonoid contents, while levels in tomatoes from 7°C and 15°C were very similar (Toor and Savage, 2006). Additionally, temperatures above 15°C have been found to be beneficial to total phenolic acid quantities in tomatoes compared with temperatures of 2˚C, 5˚C and 10˚C (Pinheiro *et al.*, 2013)

1.3.11. Vitamin C

1.3.11.1. Measurement of Vitamin C Contents in Fruit

Similar to analysis of carotenoid and phenolic compounds, Vitamin C accumulation can also be determined through HPLC detection. Additionally, like for the determination of TA, titration methods are also available for Vitamin C determination (Hernandez *et al.*, 2006). The Association of Analytical Chemists (AOAC) has a standard methodology for the determination of Vitamin C in fruit juice using a titration method with the blue indicator 2,6-di-chlorophenolindophenol (DCPIP) until a light but distinct rose pink colour appears and persists for more than five seconds (AOAC, 1995). In another titration L-ascorbic acid can also be determined directly with iodine and iodate solution, using starch as an indicator. Once all the L-ascorbic acid has been oxidised, the excess iodine solution reacts with the starch indicator producing a dark blue solution as the endpoint of the titration (Suntornsuk *et al.*, 2002)

1.3.11.2. Effect of Temperature on Vitamin C Contents of Fruit

The main biologically active form of Vitamin C found in fruit is L-ascorbic acid, and for the majority of fruits a decrease in accumulation is seen with increasing temperature (Table 4). However, this was not the case for nectarines where the levels of Vitamin C decreased with time, and losses were higher at 1°C or 4°C, than at 8°C (Aubert et al., 2014). However, cold storage did prevent Vitamin C breakdown in plums kept at 0°C which had lower rates of Vitamin C degradation compared with those kept at 5°C and 12°C (Ergun and Jezik, 2011), and in processed fruit Vitamin C degradation has been shown to be reduced at lower temperatures and this was seen at 4°C compared with 10°C in fruit salad consisting of apple, pineapple, grape and orange (Giacalone et al., 2010), and in mandarin juice exposed to 4°C, lower levels of vitamin C reduction were seen than in those exposed to 25°C (Beltrán et al., 2009).

1.4. Summary

After considering the global importance of fruit in terms of health benefits, everyday uses, the contribution to the food and drink industry and the number of people that it employs it is clear that fruit quality and shelf life is a research area which seeks attention. This is especially crucial considering that the majority of people within the world are not meeting the daily recommendation set within their respective countries, therefore it may be that increased quality and shelf life may encourage consumption.

Generally increasing temperature increases fruit taste and carotenoid contents, and increase rates of ripening seen by increased levels of colour development and firmness reduction, while lower temperatures generally reduce fruit taste but are positively associated with preserving shelf life and reducing weight loss, TSS, phenolic compound and Vitamin C losses (Figure 2). pH was found to be unaffected by temperature in the majority of the reviewed research, and the effect of temperature on TA contents varied with fruit type and also cultivar, but the majority of research showed a decline at lower storage temperature compared with higher temperatures.

Lower	**Temperature**	**Higher**
↑ Shelf Life		Shelf Life ↓
↓ Taste		Taste ↑
↓ Colour development		Colour development ↑
↓ Firmness depletion		Firmness depletion ↑
↓ Weight loss		Weight loss ↑
↓ TSS depletion		TSS depletion ↑
↓ TA		TA ↑
↔ pH		pH ↔
↓ Carotenoids		Carotenoids ↑
↓ Phenolic Compound depletion		Phenolic Compound depletion ↑
↓ Vitamin C depletion		Vitamin C depletion ↑

Figure 2 Summary of the Outcome of Temperature on Fruit Quality. Upward facing arrow shows an increase in attribute and a downward facing arrow shows a decrease in attribute, while an arrow pointing in both directions represents no change.

Temperature management is an alternative post-harvest strategy to the more expensive and specialised methods described in Section 2 in this Chapter. Improper temperature storage might explain the high number of customer complaints that supermarkets receive about fruit quality and the vast volumes of waste and costs. After considering both the temperature regimes used by ASDA, the temperatures that induce CI, and the associated effects on fruit quality, there are implications that changing temperature conditions during transport and storage can improve fruit quality in terms of taste and nutritional value, while improving or having no detrimental effect on shelf life. If the temperatures used for transport and storage of fruit can be optimised then beneficial waste aspects and cost saving for both the food suppliers and the consumer can be achieved, while also improving quality and shelf life of fruit encouraging consumption therefore increasing health benefits.

Overall Aims and Hypotheses

Aim

The overall aim of this research project was to investigate if post-harvest temperatures have an effect on the quality and shelf life of fruit and whether changing temperatures during the supply chain phase before purchase and during post-sale storage have positive effects on the overall quality and shelf life of fruit.

Hypotheses

- Temperatures above the usual supply chain temperatures during the pre-sale storage phase and/or room temperatures during the post-sale storage phase positively affect fruit sensory experience, carotenoid and phenolic accumulation, titratable acidity levels, colour development, weight loss, firmness loss, and relieve chilling injury compared with supply chain temperatures during pre-sale storage and/or refrigerator temperatures during post-sale storage.
- Supply chain temperatures during the pre-sale storage phase and/or refrigeration temperatures during the post-sale storage phase positively affect Vitamin C and total soluble solid accumulation compared with temperatures of 15°C or above during the pre-sale storage phase and/or the post-sale storage phase
- Post-harvest temperatures do not affect fruit pH levels.
- Temperatures above the usual supply chain temperatures during the pre-sale storage phase and/or room temperatures during the post-sale storage phase negatively affect fruit shelf life compared with supply chain temperatures during pre-sale storage and/or refrigerator temperatures during post-sale storage.

Chapter 2. Preliminary Research: The Effects of Post-Sale Room Temperature or Refrigerator Temperature on Ten Fruit

2.1. Introduction

Poor temperature management is a major postharvest factor that affects fruit flavour and aroma (Sargent et al 1997; Moretti et al 1998). Table 6 summarises the temperatures that have been found to cause CI in tomatoes, citrus fruit, peaches, plums and nectarines. The consumer generally stores fruit in the refrigerator (5-10˚C) after purchase (Li-Cohen and Bruhn, 2002) in an effort to increase shelf life and preserve quality. However, since this means that tomatoes are kept below 13°C, peaches, plums and nectarines above 0°C, and citrus fruits most likely above 5°C there are implications that these fruit will suffer from CI, and therefore have depleted quality and shelf life.

Table 6 Temperatures that Cause Chilling Injury in Tomatoes, Citrus Fruits and Stone Fruits.

Fruit	Temperatures that Cause CI	Source
Tomato	<13°C	(Hobson, 1987; Maul *et al.*, 2000)
Citrus Fruit	<2-5°C	(Sanchez-Ballesta *et al.*, 2003)
Stone Fruit (Peaches, Plums and Nectarines)	2.2-7.6°C (0˚C is recommended)	(Harding and Haller, 1934; Smith, 1934; Crisosto *et al.*, 1999)

Strawberries and grapes are more chilling tolerant than other fruits, however, storage in the refrigerator may impede the development of aroma volatiles and beneficial nutritional compounds, such as antioxidants (Ayala-Zavala et al 2004).

Aims and Hypotheses

The aim of the research was to investigate if storage at room temperature or in a refrigerator is beneficial to shop bought round, cherry and plum tomatoes (*Lycopersicon esculentum* Mill), peaches (*Prunus persica*), plums (*Prunus domestica*), nectarines (*Prunus perscia* var. nectarina*)*, strawberries (*Fragaria ananassa*), mandarins (*Citrus unshiu Marcovitch*), and red and white grapes (*Vitis vinifera*). This study also aimed to find out how many fruits are required per test, and collectively for the whole experiment, as well as inform about which species and methods are suitable for the following studies. These fruit were chosen as they were either one of ASDA's top sold fruit species of 2011 (tomatoes, strawberries and mandarins), or they have been reported problematic by ASDA in terms of postharvest quality and shelf life (peaches, plums, nectarines and grapes), leading to large volumes of waste.

Hypothesis

- Refrigeration temperatures (6±1°C) cause CI in tomatoes, peaches, plums, nectarines and mandarins.
- Temperatures above 13˚C improve tomato quality in terms of taste.

Research questions

- Are the methods used suitable for all ten fruit?
- Is the number of fruit samples used ample for each fruit study?
- For which fruit species will higher temperatures produce fruit of better quality than low temperatures?
- For which fruit species will higher temperatures reduce fruit shelf life than lower temperatures?
- For which fruit species will refrigeration temperatures cause CI?

2.2. Materials and Methods

2.2.1. Fruit

Fruit were purchased from a local supermarket. Six punnets were used for all fruits, except ten punnets of cherry tomatoes, two net bags of mandarins and two punnets of plum tomatoes. Half of each fruit type was left out on the work surface of the experimental kitchen at room temperature (RT) (22±2°C), and the other half was kept in a domestic refrigerator (F) (6±1°C), both in the Agriculture Building, Newcastle University. Fruit was sampled on the day of purchase (day zero) and then every Monday, Wednesday and Friday until there were no samples remaining. Average relative humidity was 40.7% for F treatment, and 28.5% for RT treatment.

2.2.2. Weight loss (%)

Fruit were weighed in punnets (ae Adam equipment, Milton Keynes, UK). After deducting the weights of each punnet/net bag, total weight loss (%) was calculated using the following formula:

$$\text{Weight loss (\%)} = \frac{\text{initial weight} - \text{new weight}}{\text{initial weight}} \times 100$$

Rate of weight loss for each fruit was found using the line equation from the trend line of the data in a scatter plot.

2.2.3. Taste Test

Three fruits from each temperature treatment were taste tested by the researcher, except for the stone fruits, mandarins and round salad tomatoes, where one slice/segment from two fruits was taste tested. Fruits were scored from 1-5: 1= very bad, 2= bad, 3= fair, 4=good, 5= excellent. Water was sipped between tasting each fruit sample.

2.2.4. Shelf Life

Shelf life was measured as the final day at which the fruits were acceptable to be taste tested by the researcher, therefore wrinkly, decayed or overly soft fruit were seen as unacceptable and at the end of their shelf life.

2.2.5. Firmness

Firmness was measured based on a method by Thybo et al., (2005) using an instrumental texture analyser (Lloyd, PA, USA). Two positions were used; position one being the bottom of the fruit facing upwards (blossom end), and position two being the side of the fruit (after the fruit was turned clockwise). Using a 659cm^3 plate, compression was measured at 10mm/min to a load of 10N, and using the load deformation curve created, the slope of the curve between 20% and 80% of the maximum deformation was calculated (N/mm). To measure fruit penetration an 8mm cylindrical probe with a convex end and a crosshead speed of 8.33 x 10^{-4} ms^{-1} was used. Penetration values were calculated from the load-deformation curve as the maximum load before penetration into the flesh. For the majority of fruit types, six samples from each treatment were used, however for peaches, plums and nectarines only three per treatment were used as fewer samples were available

2.2.6. Chemical Constitutes: pH, TSS and TA

The same fruits that had been tested for firmness were then tested for pH, TSS and TA contents. Strawberries, however, were not analysed for chemical constitutes as methods had not been developed by this time as they were the first fruit to be tested. Fruit were cut, blended and centrifuged (accuSpin 3R, Fischer Scientific, Leicestershire, UK) using 4000rpm at 5°C for 20 minutes. The supernatant was removed and filtered through Whatman No.1 filter paper (Whatman, Kent, UK). For pH identification supernatant was analysed using a pH probe (HANNA instruments, RI, USA). TSS contents were investigated by testing three drops of supernatant on a digital refractometer (Bellingham and Stanley, Basingstoke, UK), and results were expressed as ˚Brix. For TA, 10ml of fruit supernatant was diluted to 250ml with deionised water (NANOpure Diamond, Barnstead, CA, USA). 100ml of the solution was then titrated with 0.1N sodium hydroxide using 0.3ml of phenolphthalein to a pink colour that persists for 30 seconds.

Citric acid was used as a standard for tomatoes and mandarins, malic acid for peaches, plums and nectarines, and tartaric acid for grapes. TA contents were calculated using the appropriate milliequivalent factors (0.064, 0.067 and 0.075 for citric, malic and tartaric acid respectively). Results were expressed as g/100g FW of the respective acid.

2.3. Statistical Analysis

A p-value of less than 0.05 was considered significant. Repeated measures General Linear Model (GLM) was used for the data. Normality of data was checked using probability of residuals and residuals versus fits plots. If data were not normal they were logarithmically transformed. No standard error is shown on the graphs for the chemical constitutes as the three or six samples were collated at each sample day to provide sufficient supernatant for analysis.

2.4. Results

2.4.1. Nectarines, Peaches and Plums

The results for the quality analysis for the peaches, plums and nectarines used during this study were very similar and general trends were seen for most measurements, and so only nectarines have been shown as a representation of the data, this is except for the taste scores, and TSS and TA accumulation, which is explained.

2.4.1.1. Taste

The taste scores decreased as the study progressed for nectarines, peaches and plums. For nectarines, fruit from F treatment generally received lower taste scores than those from RT treatment, although by day ten similar scores were seen for all fruit regardless of treatment (Figure 3).

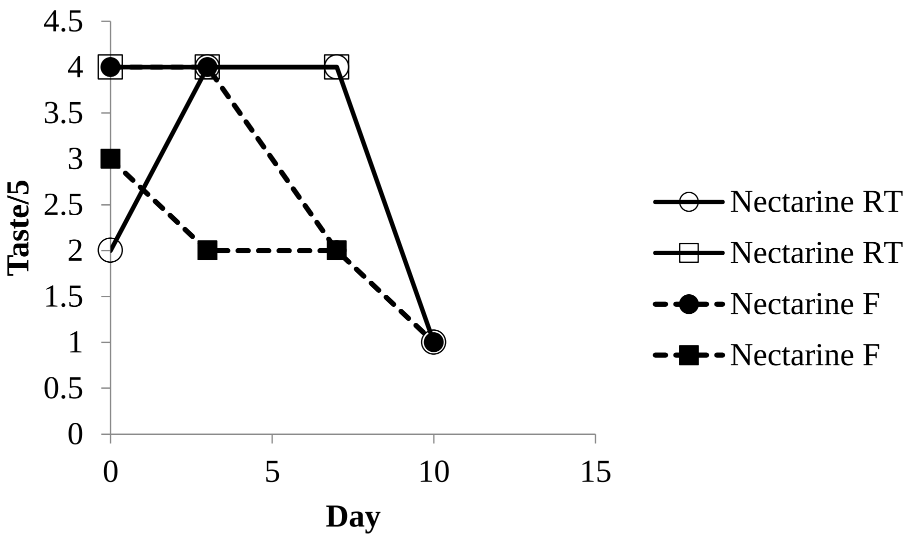

Figure 3 Taste Scores for Nectarines. Taste score out of 5 for shop bought nectarines kept at either room 22°C (RT) or refrigeration 6°C (F) temperature.

The results for the peach taste scores from RT and F treatment increased between day zero and three, although a decrease in scores was seen after day three for fruit from F treatment (RT peaches were not tasted after day three) (Figure 4). For plums, those from RT treatment generally had lower taste scores than those from F treatment (Figure 5), most noticeably for the first three days of the study.

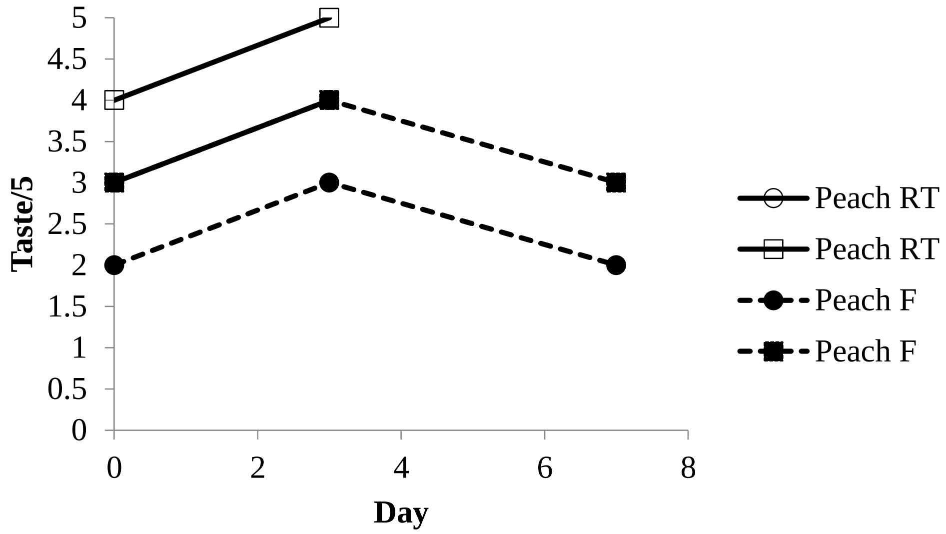

Figure 4 Taste Scores for Peach. Taste score out of 5 for shop bought peaches kept at either room 22˚C (RT) or refrigeration 6˚C (F) temperature.

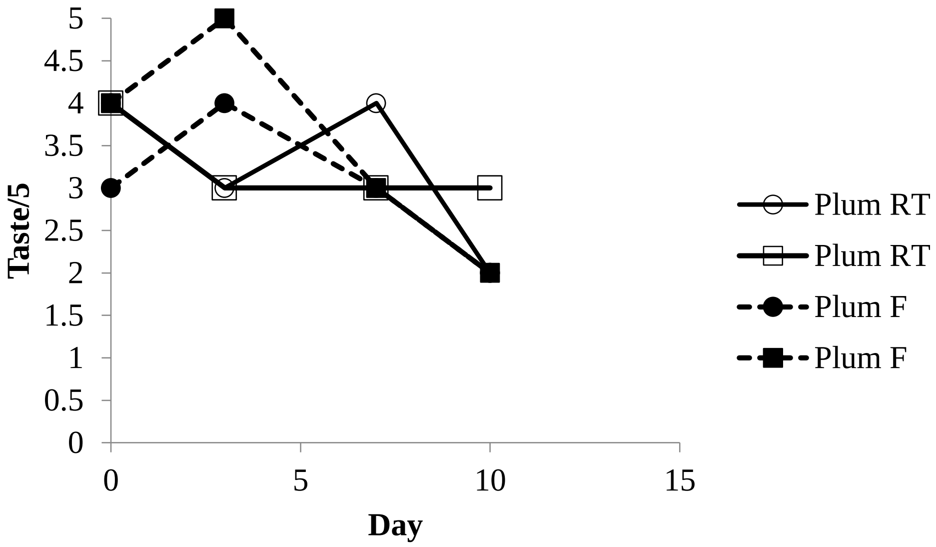

Figure 5 Taste Scores for Plums. Taste score out of 5 for shop bought plums kept at either room 22˚C (RT) or refrigeration 6˚C (F) temperature.

Nectarine quality in terms of taste was postively affected by storage at RT treatment. Peach taste was also improved by storage at RT treatment, however, since peaches from RT treatment were only tasted until day three, it is unknown what further effects RT treatment would have on peach taste in the long run. Plum taste, conversly, did not react positively to RT treatment and those kept at F treatment had better quality in terms of taste or had preserved taste scores.

2.4.1.2 Shelf life

The shelf life of peaches was much shorter than that of nectarines and plums, and peaches from RT treatment were not taste tested after day three and those from F treatment were not taste tested after day seven as by these time points they had become shrivelled and soft, while nectarines and plums both lasted until day ten, irrespective of treatment.

2.4.1.3 Firmness

For nectarines, peaches and plums from both treatments a decline in deformation value was seen as the study progressed since less force was required to compress the fruits as they softened over time. However, this was most prominent in fruit from RT treatment, most noticeably between day zero and three, as seen for nectarines in Figure 6, and treatment was found to have a significant effect on the deformation values for all stone fruit (all $p<0.001$), with those from RT treatment being very soft by day 10 (1.6 N/mm) and an interaction between day and treatment was seen ($p=0.007$, $p=0.035$ and $p<0.001$, for nectarines, peaches and plums respectively).

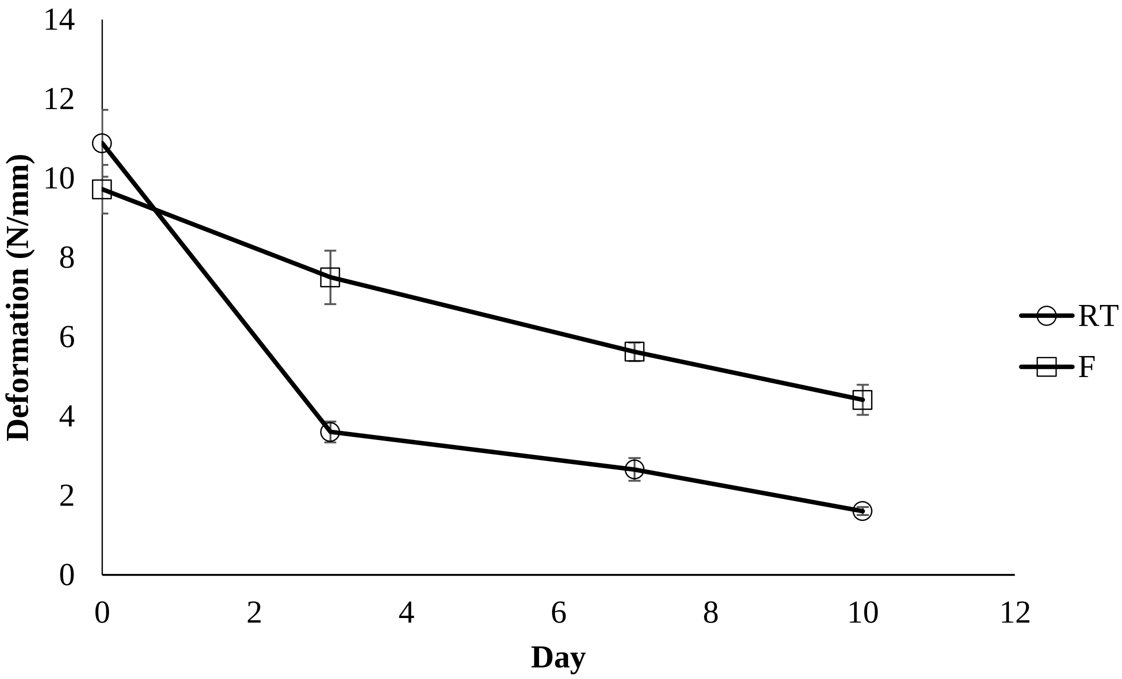

Figure 6 Deformation of Nectarines. Mean deformation values (N/mm) of shop bought nectarines kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature. Bars represent standard error.

The results for penetration followed a similar trend as to what was seen for the deformation of the stone fruits, with fruits from both treatments decreasing in penetration values as the study progressed, and nectarines, peaches and plums from RT treatment having the greatest firmness reduction compared with those from F treatment (Figure 7). Treatment was found to have a significant effect on penetration ($p<0.001$, $p=0.001$ and $p=0.026$ for nectarines, peaches and plums respectively)

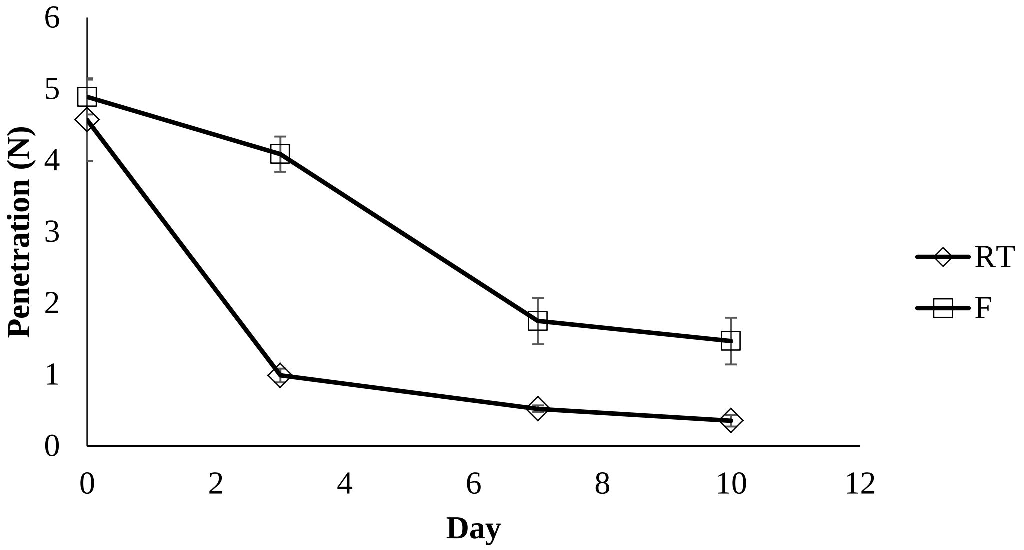

Figure 7 Firmness (Penetration) of Nectarines. Mean penetration values (N) of shop bought nectarines kept at either room 22°C (RT) or refrigerator 6°C (F) temperature. Bars represent standard error.

In terms of firmness retention, stone fruit quality reacted positively to storage at F treatment. This method was an effective method of showing texture differences between stone fruit from different temperature treatments. Reductions in stone fruit firmness were seen in both treatments where fruits became soft and of improved quality and optimal for eating, however it was considerably quicker in those from RT treatment where firmness levels decreased considerably until the point that they were of poor quality much earlier than those from F treatment.

2.4.1.4 Chemical Constitutes: TSS, TA and pH

TSS levels were significantly higher in nectarines from RT treatment as compared with those from F treatment (p=0.002) (Figure 8) and an interaction was seen between treatment and day (p<0.001). TSS accumulation was not the same for plums and peaches as it was for nectarines, and no significant differences were seen between fruit from different treatments (p=0.327 and p=0.556 for peaches and plums respectively).

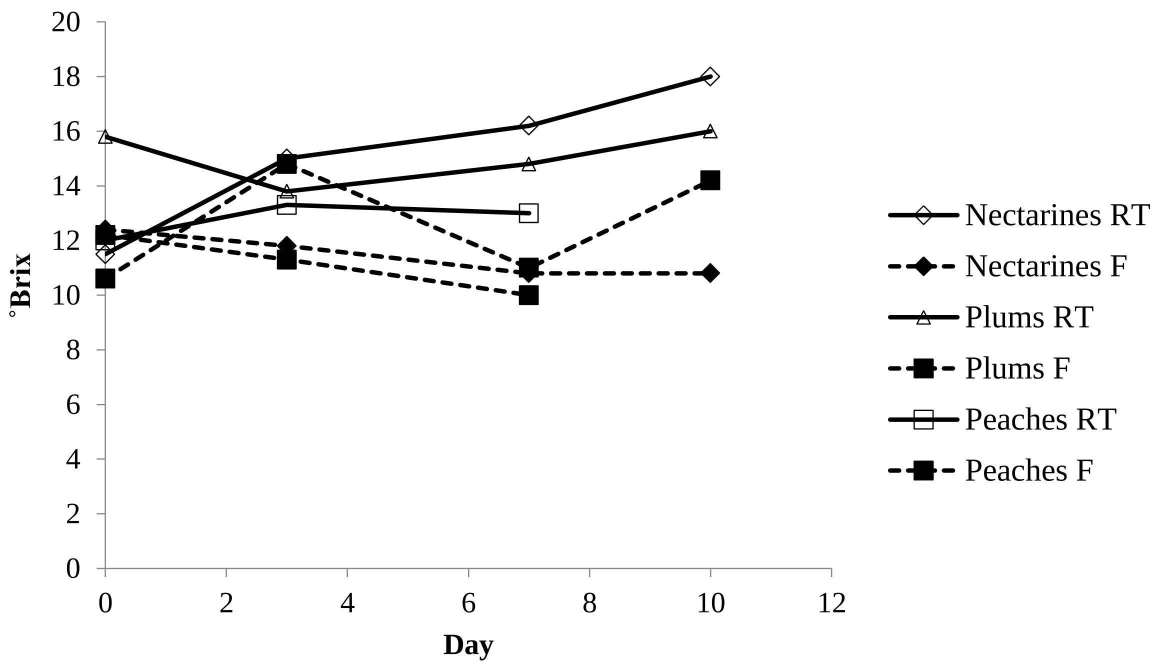

Figure 8 Total Soluble Solid Content of Nectarines, Peaches and Plums. TSS values (°Brix) of shop bought stone fruit kept at either room 22°C (RT) or refrigerator 6°C (F) temperature.

Levels of TA had only small changes as the study progressed, and no significant differences were noticed for any of the factors investigated for nectarines and peaches (Figure 9). For plums, unlike the other stone fruit, levels of TA were significantly affected by treatment (p=0.019), with those from F treatment generally having higher levels, except for day ten where the inverse is seen. Day was also found to have a significant effect on the TA contents of plums (p=0.005), and an interaction was seen between the day and treatment (p=0.006).

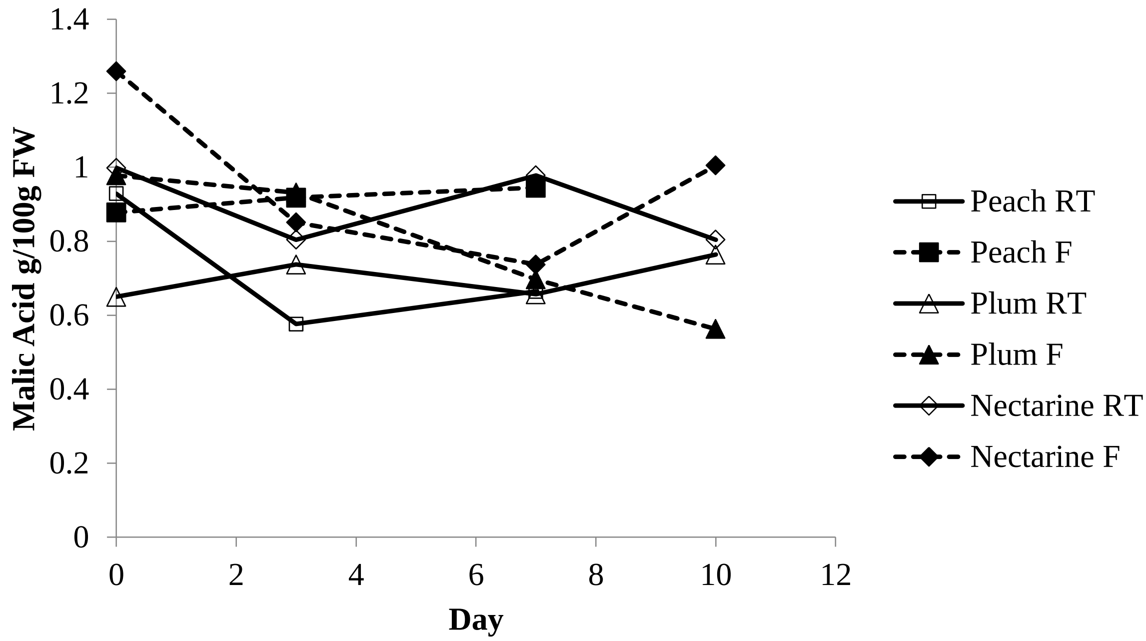

Figure 9 Titratable Acidity of Nectarines, Peaches and Plums. Mean titratable acidity (Malic acid g/100g FW) of shop bought nectarines kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

pH levels responded similarly to treatment for all stone fruits, and were relatively constant between day zero and seven, although an increase was seen in fruits from RT treatment at day ten (Figure 10). No significant differences were noticed for any of the factors investigated for any of the stone fruits.

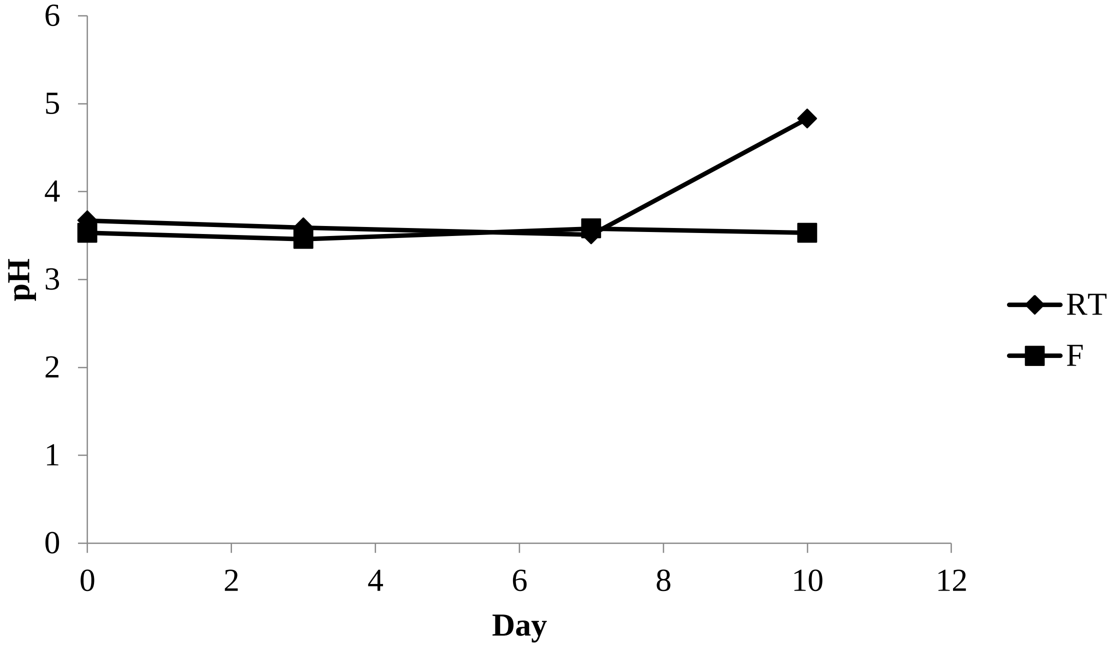

Figure 10 pH of Nectarines. pH of shop bought nectarines kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature. No significant differences were seen for nectarines, peaches and plums for treatment (p=0.239, p=0.457 and p=0.693 respectively), day (p=0.854, p=0.663 and p=0.119 respectively) or the interaction between treatment and day (p=0.273, p=0.409 and p=0.148 respectively)

In terms of chemical constitutes, TSS values continued to increase in stone fruit from RT treatment giving more sweet fruit and therefore higher quality as compared with those from F treatment, while acidity levels in fruits from both treatments remained relatively unaffected by temperature treatments, except for in plums where F treatment produced plums with higher levels of TA.

2.4.2. Weight Loss (%)

Nectarines have been used as an example of the typical weight loss results for the stone fruits, and cherry tomatoes as a representation of the weight loss of the plum tomatoes. Out of the grapes tested only the results of green grapes are shown for the same reason, and since the results for round salad tomatoes and mandarins were similar, only the results of round salad tomatoes are discussed.

Weight loss was higher in all the fruit that was kept at RT treatment compared with those kept at F treatment, and the rate of weight loss was also highest in fruit kept at RT treatment compared with F treatment, regardless of fruit type (Table 7). Treatment was found to have a highly significant effect on weight loss of all the fruits analysed (all $p<0.001$).

Table 7 Rate of Weight Loss of Nectarines, Green Grapes, Strawberries, Round Salad Tomatoes and Cherry Tomatoes (% per day). Shop bought fruit was kept at either room 22°C (RT) or refrigerator 6°C (F) temperature.

Fruit	Rate of Weight Loss (% per day)		Time until the End of the Study (days)	
	RT	F	RT	F
Nectarines	3.13	0.67	10	10
Green Grapes	2.58	0.57	15	17
Strawberries	8.39	1.22	6	8
Round Salad Tomatoes	0.81	0.13	18	18
Cherry Tomatoes	1.13	0.31	18	18

An interaction was found between day and treatment for all fruit ($p=0.042$ for plum tomatoes, $p<0.001$ for all others) except round salad tomatoes ($p=0.062$). Strawberries had the greatest rate of weight loss at RT treatment out of all the fruits studied (Table 7). Moreover, strawberries also had the greatest rate of weight loss out of all the fruits studied when kept at F treatment. This was most likely due to their high metabolic rates (Ayala-Zavalaa *et al.*, 2004). Round salad tomatoes and cherry tomatoes from RT treatment did not have such high levels of weight loss, although RT treatment still caused higher levels of weight loss than F treatment. Round salad tomatoes had the lowest rates of weight loss when stored at either treatment out of all the fruits in investigated (Table 7), suggesting that round salad tomatoes are the most suited in preserving quality in terms of weight out of all the fruits analysed.

2.4.3. Grapes and Strawberries

Results for green grapes are mainly shown, and those for red grapes and strawberry have not been included as general trends were seen, except for taste, deformation and penetration.

2.4.3.1. Taste

Taste generally decreased in green grapes, red grapes and strawberries from RT treatment as the study progressed. A large amount of variation is seen in the taste scores of the grapes, most likely to variation within the batch. For green grapes, taste scores were generally slightly lower for those that had been exposed to F treatment compared with RT treatment, although by the end of the experiment green grapes from F treatment had similar taste scores to those at day zero (Figure 11).

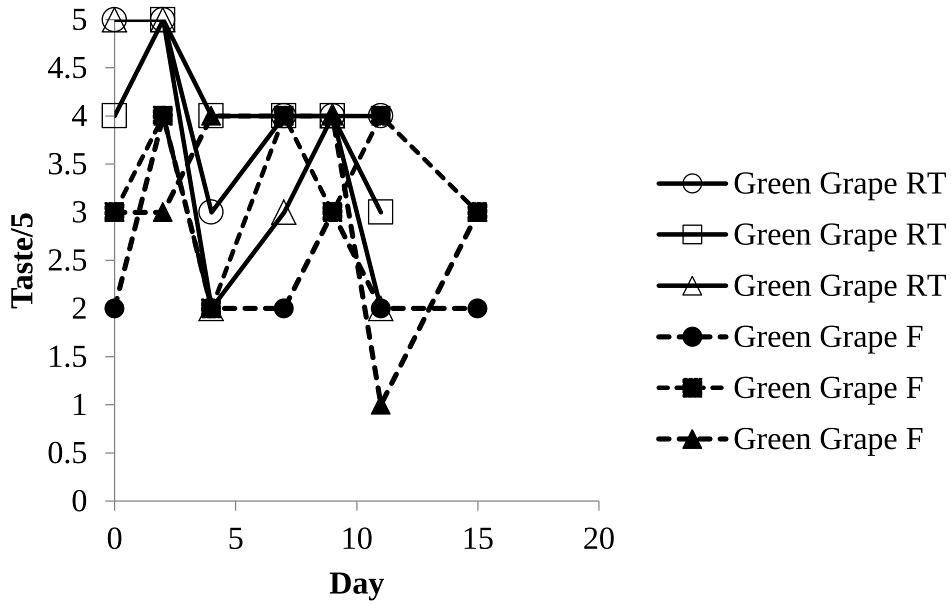

Figure 11 Taste Scores for Green Grapes. Taste score out of 5 for shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

The taste of red grapes appeared to be preserved by F treatment and on average little reduction was seen for the first seven days for fruit from this treatment, however, red grapes from RT treatment generally had higher scores than those from F treatment for the nine days that they were analysed, except at day seven (Figure 12).

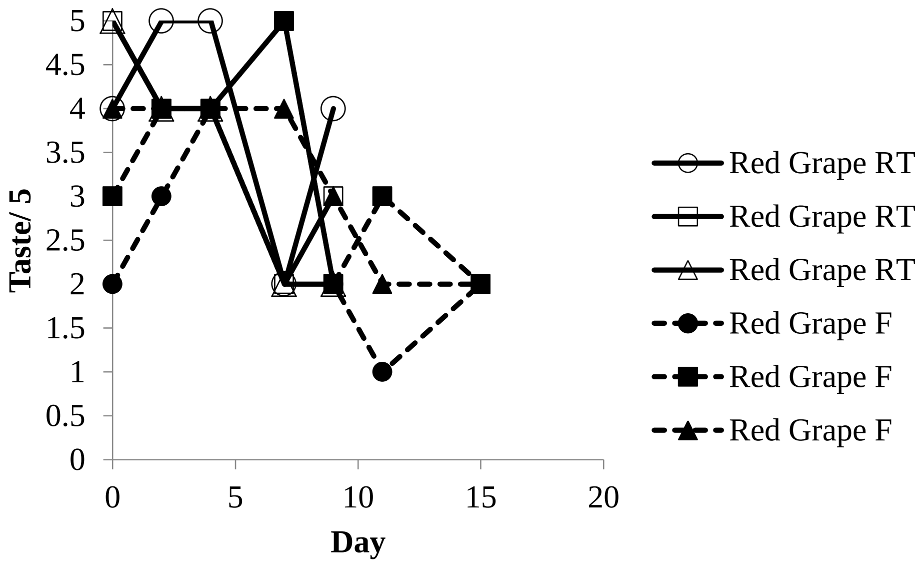

Figure 12 Taste Scores for Red Grapes. Taste score out of 5 for shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

Strawberry taste was generally higher for fruit from RT treatment (Figure 13); however, fruits from this treatment were only tasted until day two as they had become unacceptable for consumption by day four. Generally, little change was seen in the taste scores for strawberries from F treatment for the first seven days, although a decrease was seen by day nine.

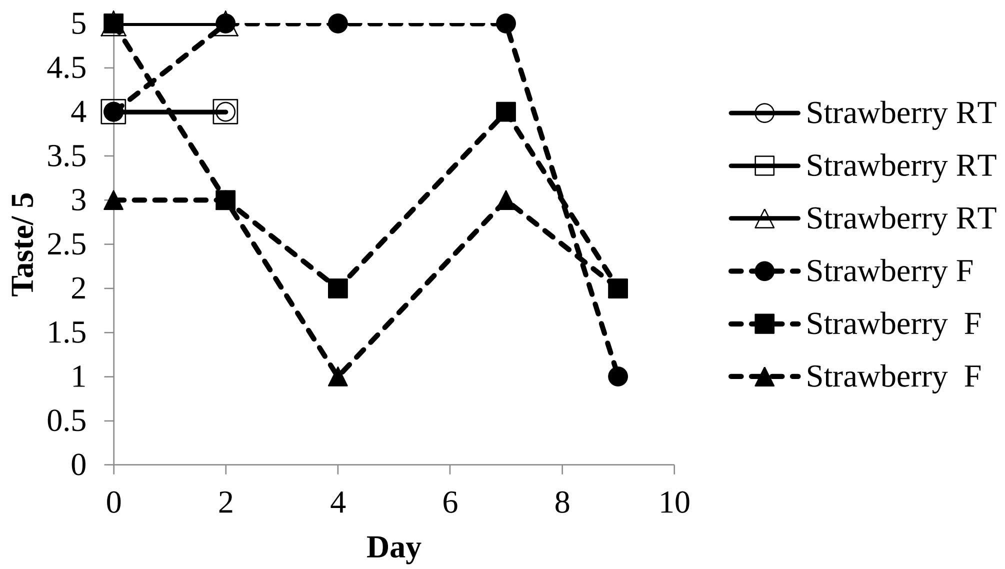

Figure 13 Taste Scores for Strawberries. Taste score out of 5 for shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

The quality attributes of grapes and strawberries in terms of taste were all increased during storage at RT treatment, while F treatment produced fruits with lower taste scores.

2.4.3.2. Shelf life

Shelf life was severely reduced when strawberries were kept at RT treatment and strawberries from RT treatment were not analysed for taste at day four and onwards, as by this point they were either showing visual signs of grey mould *(Botrytis cinerea)* or were visibly unappealing, while those from F treatment were taste tested until day nine, and this was probably why no significant differences were seen between the taste scores of fruit from different treatments. Green grapes had a longer shelf life than red grapes by two days for those kept at RT treatment, and six days for those kept at F treatment.

Although strawberries from RT treatment were not taste tested past day two, strawberries from this treatment continued to be analysed for other quality measurements until day seven, as although they were not fit for consumption as they were beginning to shrivel, they were still suitable for analysis as they were not mouldy. Similarly, for red grapes and green grapes, those from RT treatment were analysed for an extra six and four days respectively, while those from F treatment for an extra two and eight days respectively.

2.4.3.4. Firmness

Deformation values declined with time in grapes from both treatments, and in general those from RT treatment had values that were slightly lower (Figure 14). The GLM analysis showed all factors analysed to be significant (all p<0.001, except p=0.479 for the effect of 'day' on the deformation of red grapes). For strawberries a difference was seen, and strawberries from F treatment appeared to increase in firmness in terms of deformation as the study progressed, but by day nine deformation values were similar to those recorded at day zero, while values for those from RT treatment had decreased. However, no statistical significance was seen between strawberries from different treatments (p=0.724), although an interaction between day and treatment was seen (p=0.020).

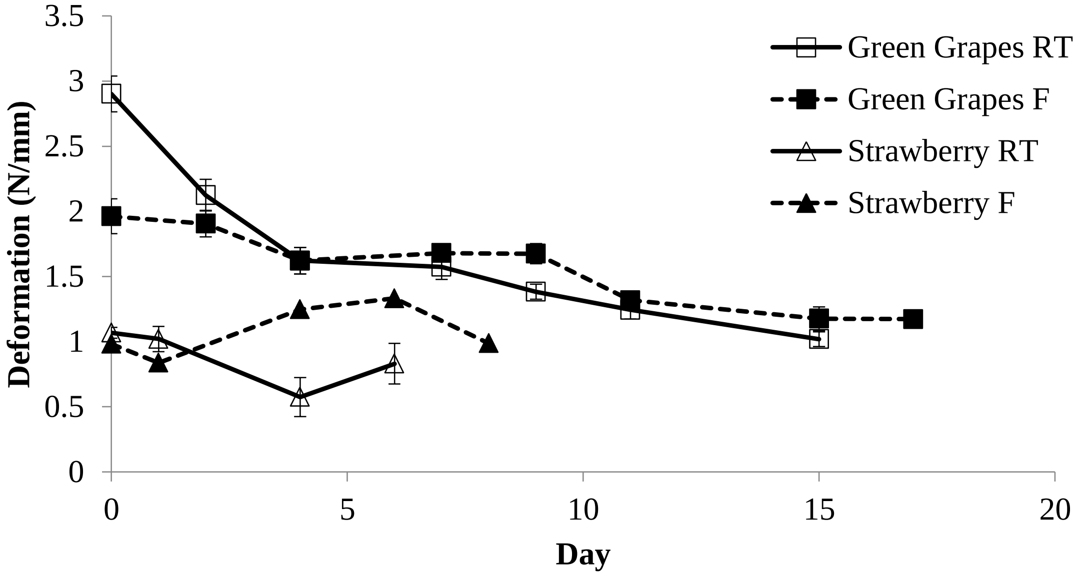

Figure 14 Deformation of Green Grapes and Strawberries. Mean deformation (N/mm) of shop bought green grapes kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature. Bars represent standard error.

Penetration values were higher in grapes that had been kept at F treatment (p=0.030 and p=0.012 for green and red grapes respectively), although declines were seen in penetration values for grapes from both treatments (Figure 15). Similar to the GLM results for the deformation of green and red grapes, day and the interaction between day and treatment were also found to have a significant effect on fruit penetration (p<0.001 and p=0.025 for day, and p=0.042 and p=0.049 for the interaction between day and treatment for green and red grapes respectively).

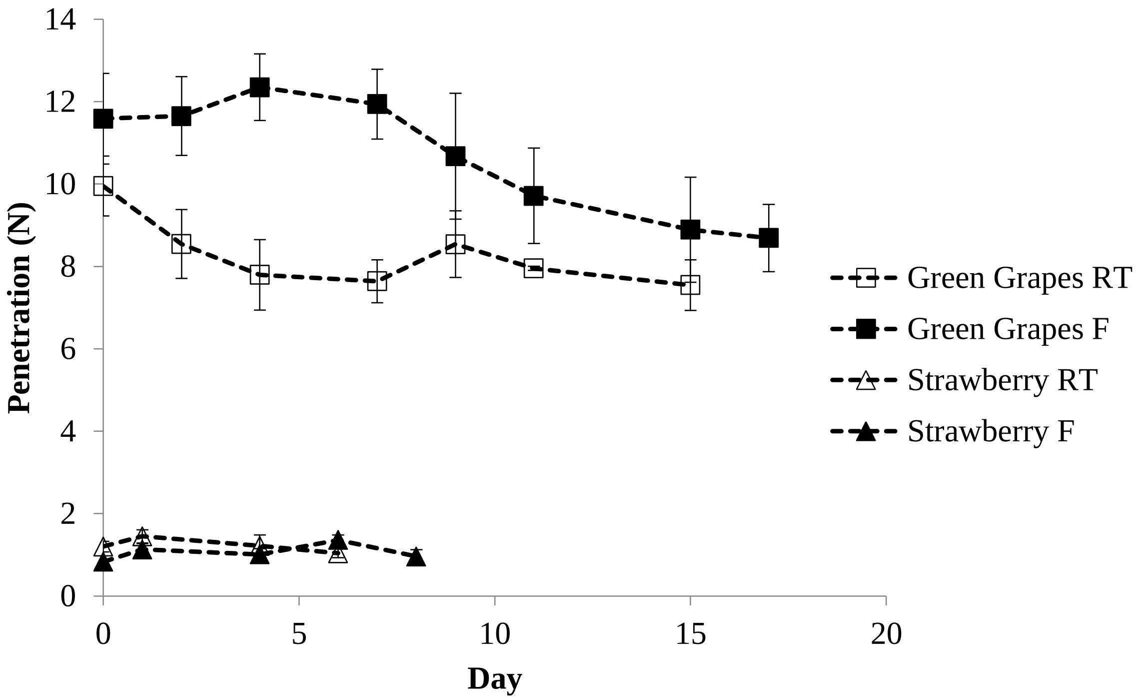

Figure 15 Firmness (Penetration) of Green Grapes and Strawberries. Mean penetration (N) of shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature. Bars represent standard error

In comparison to the penetration values of the grapes, those of the strawberries were considerably lower. Between day zero and four strawberries from RT treatment had higher penetration values by 44%, 28% and 20% for day zero, day one and day four respectively, while at day seven strawberries from F treatment were higher. No penetration was recorded at day nine for strawberries from RT treatment as by this point they were all decayed. However, treatment was not found to have a significant effect on strawberry penetration values (p=0.321), while day was (p=0.025), and an interaction between day and treatment was seen (p=0.042).

The firmness methods used during this study were difficult to use on grapes and strawberries due to their small size, and it was particularly difficult to use on strawberries due to their characteristic bulbous top and narrow tip. This may explain why the results for strawberries do not show clear differences between treatments. Nevertheless, it was still an effective method of showing texture differences between grapes from different temperature treatments.

In terms of fruit firmness, reductions were seen in grapes and strawberries from both treatments, however it was considerably more severe in those from RT treatment where firmness levels decreased considerably until the point that they were of poor quality much earlier than those from F treatment.

2.4.3.5. Chemical Constitutes: TSS, TA and pH

Strawberries were not analysed for TSS, TA and pH as they were the first fruits analysed and methods had not been developed in time. The TSS values of both types of grapes were similar. There was a slight increase in TSS values of the grapes as the study progressed (Figure 16). In general TSS values were higher in grapes that had been kept at RT treatment.

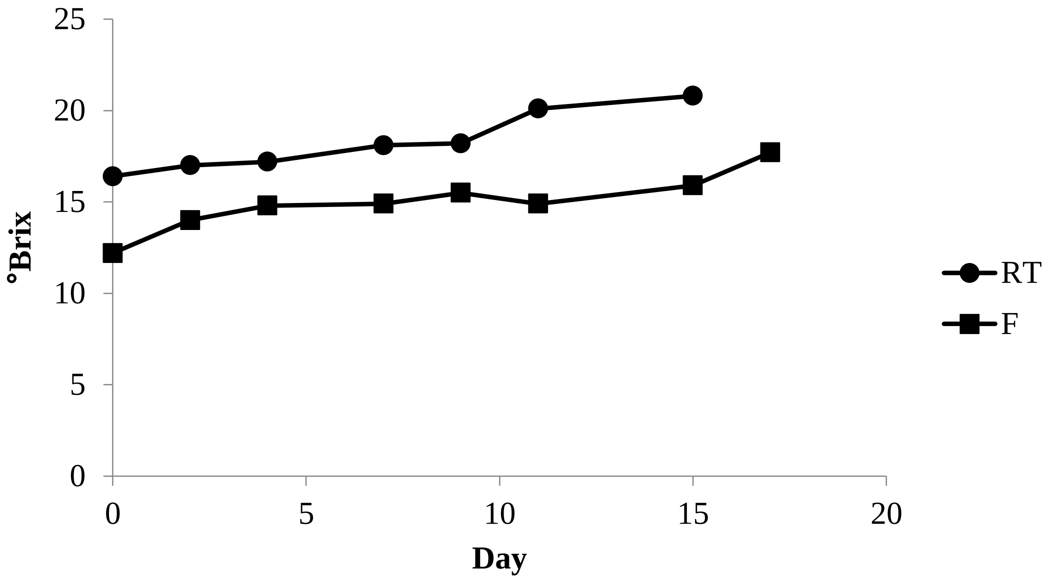

Figure 16 Total Soluble Solid Content of Green Grapes. TSS values (°Brix) of shop bought green grapes kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

Both day and treatment were found to have a significant effect on TSS contents of green grapes ($p<0.001$), but only treatment had a significant effect on the TSS accumulation of red grapes ($p<0.001$), and this may have been caused by greater water loss through evaporation at the warmer temperatures of RT treatment compared with F treatment. An interaction between the treatment and day was seen for red grapes ($p=0.001$).

TA accumulation increased in grapes from all treatments. Interestingly red grapes generally had higher levels of tartaric acid than green grapes and larger amounts of variation are seen, and this could have been due to variation within the batch of red grapes. TA levels of green grapes were not affected by treatment or day ($p=0.088$ and $p=0.539$ respectively) (Figure 17). For red grapes TA levels were generally higher in fruits from RT treatment compared with F treatment ($p=0.001$), while neither day ($p=0.619$) nor an interaction between day and treatment ($p=0.182$) were found to be significant factors.

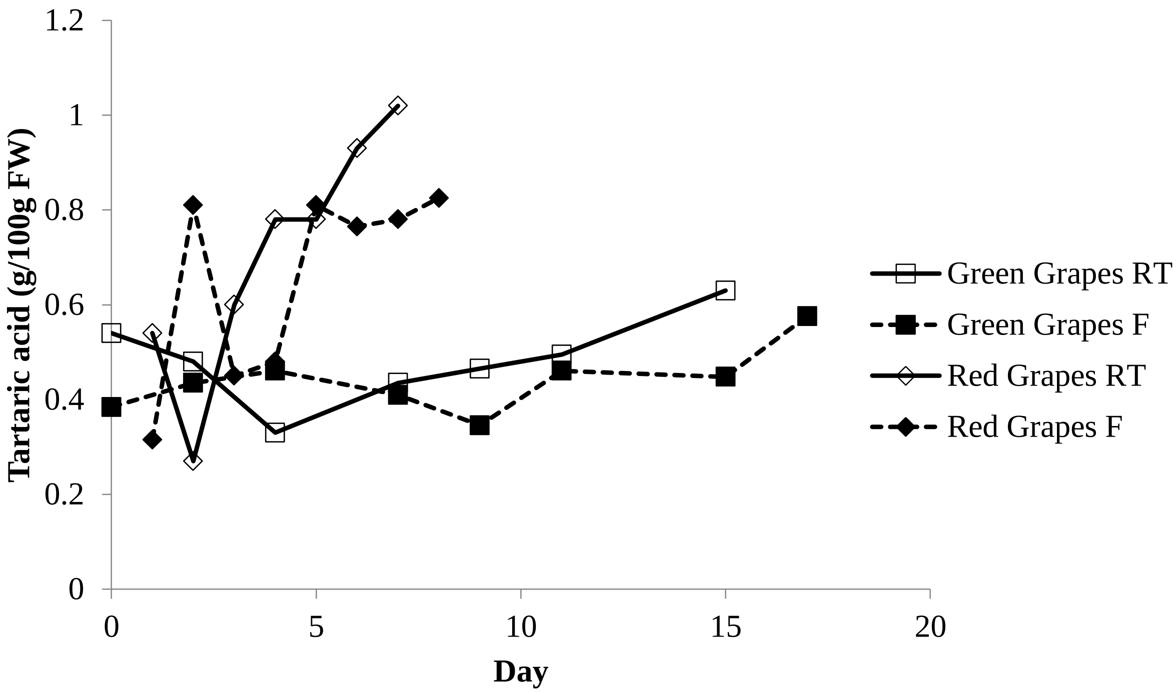

Figure 17 Titratable Acidity of Green Grapes and Red Grapes. Titratable acidity (Tartaric acid g/100g FW) of shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

pH contents of red and green grapes were similar. pH levels were higher in grapes from RT treatment, but this was only by a very small degree (≤7%), and no significant differences were found for both red and green grapes for any of the factors investigated (Figure 18).

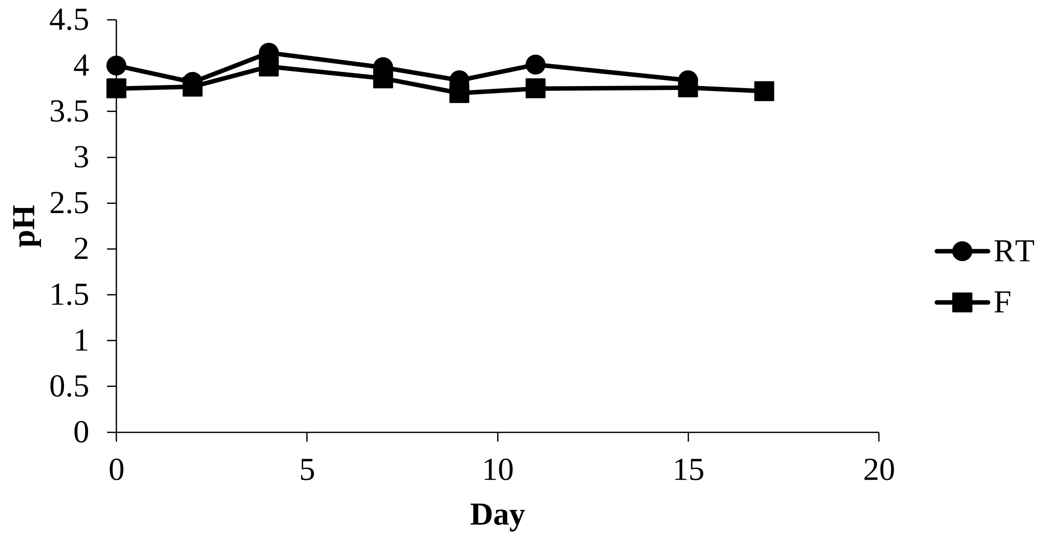

Figure 18 pH of Green Grapes. Shop bought fruits were kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature. No significant difference was seen from the repeated measures GLM output for green or red grapes for treatment ($p=0.274$ and $p=0.689$ respectively), day ($p=0.131$ and $p=0.279$ respectively) or the interaction between treatment and day ($p=0.925$ and $p=0.198$ respectively).

Quality, in terms TSS contents, was increased during storage at RT treatment, while acidity and pH levels in grapes from both treatments remained relatively unaffected by temperature treatments, although TA accumulation was higher in red grapes from RT treatment.

2.4.4. Round Salad Tomatoes and Mandarins

The results for round salad tomatoes are a good example of the data trends that were seen for mandarins, and so for this reason the data for round salad tomatoes are mainly discussed as a representation, except for changes in taste and TA contents.

2.4.4.1 Taste

Taste declined in round salad tomatoes (Figure 19) and mandarins (Figure 20) from both treatments as the study progressed. For round salad tomatoes the taste scores of fruits from RT treatment were generally higher or equal to the taste scores of fruit from F treatment (Figure 19).

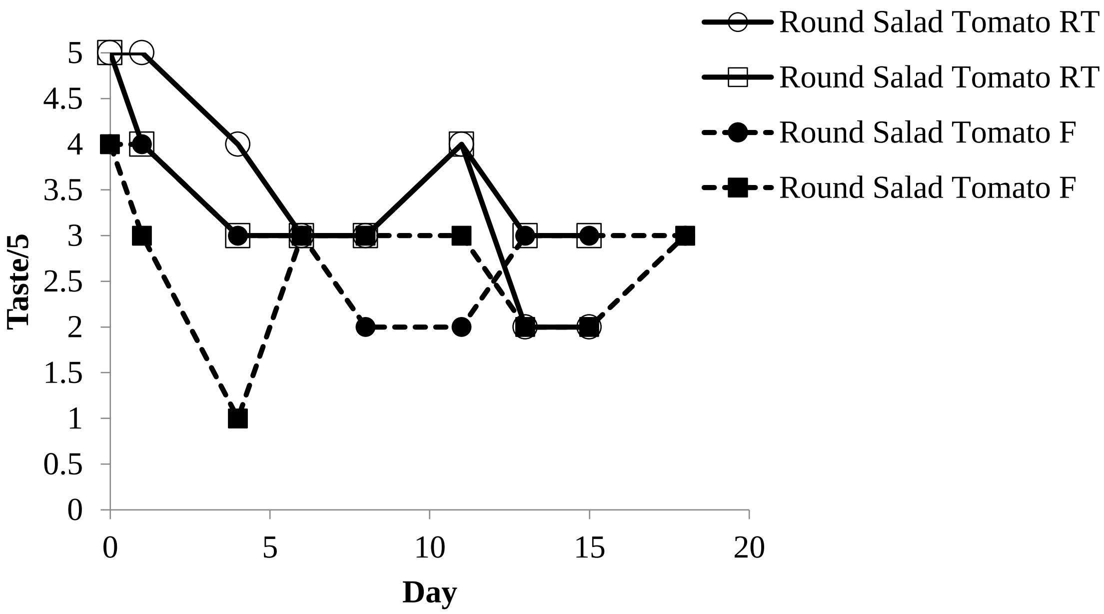

Figure 19 Taste Scores of Round Salad Tomatoes. Taste score out of 5 for shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

For mandarins, fruits from RT treatments generally had lower taste scores than those from F treatment, and by the end of the study mandarins from F treatment were higher in taste scores than those from RT treatment.

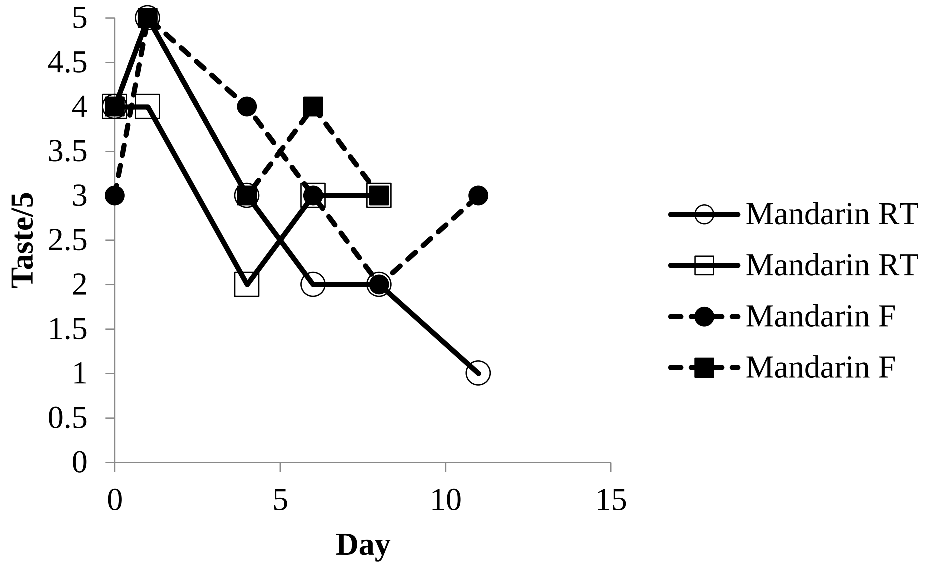

Figure 20 Taste Scores of Mandarins. Taste score out of 5 for shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

Round salad tomato quality in terms of taste was increased during storage at RT treatment. However, this was not the case for mandarins where F treatment appeared to have a positive effect on preserving mandarin taste compared with RT treatment. Since tomatoes are climacteric fruit and mandarins are non-climacteric fruit, the differences seen here may be an example of the differences in responses to temperature seen between different types of ripening.

2.4.4.2 Shelf life

Mandarins had a shorter shelf life than round salad tomatoes by four days and seven days for fruits from RT and F treatment respectively. Interestingly, mandarins from both treatments had the same shelf life of eleven days, while for round salad tomatoes; fruits from F treatment had a longer shelf life than those from RT treatment by three days. However, round salad tomatoes from both treatments were tested for other quality measurements until day eighteen, although round salad tomatoes from RT treatment were only tasted until day fifteen as they had become wrinkly. Mandarins were analysed for TSS, TA and pH until day eight but tasted until day eleven. This was since sample numbers began to run low and taste results was seen as more important than those for TSS, TA and pH during this study.

2.4.4.3. Firmness

Round salad tomatoes and mandarins were not analysed for firmness during this study due to the Lloyd's compressor being unavailable.

2.4.4.4. Chemical Constitutes: TSS, TA and pH

The TSS of the round salad tomatoes and mandarins remained relatively stable (Figure 21), and no statistically significant effects were found for any of the factors analysed, although on a number of occasions RT treatment produced fruit with higher TSS values, as can be seen for round salad tomatoes in Figure 21.

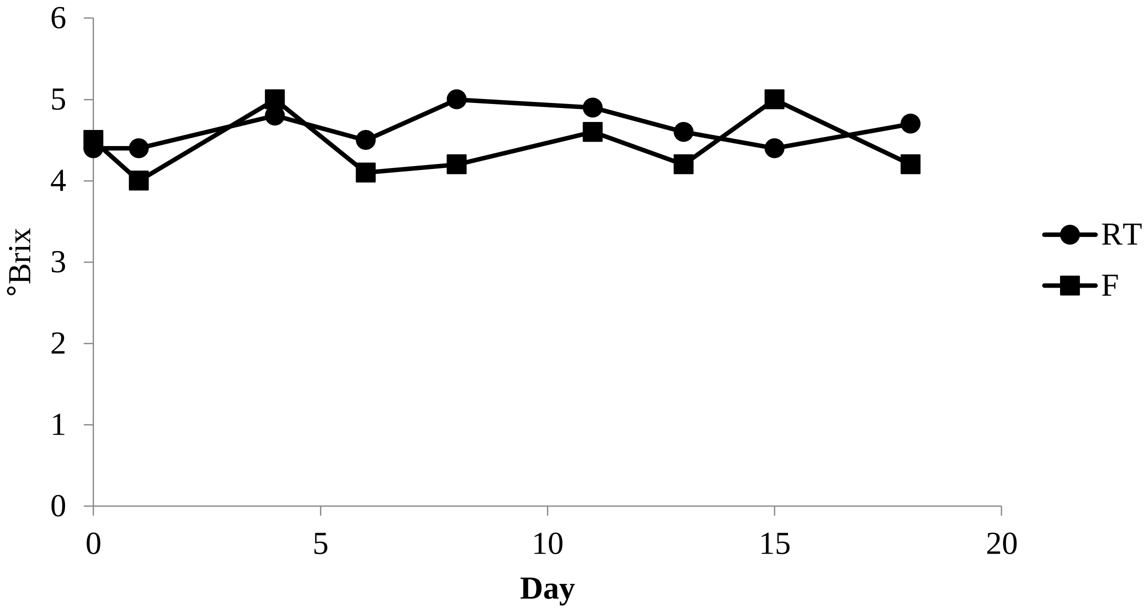

Figure 21 Total Soluble Solid Contents of Round Salad Tomatoes. TSS values (°Brix) of shop fruits kept at either room 22° (RT) or refrigerator 6°C (F) temperature. For round salad tomatoes and mandarins treatment was not found to have a significant effect (p=0.580 and p=0.456 respectively), neither was day (p=0.499 and p=0.497 respectively) nor their interaction (p=0.919 and 0.980 respectively)

TA levels in mandarins were considerably higher than those of round salad tomatoes, most noticeably at days six and eight (Figure 22). The TA levels of round salad tomatoes did not increase or decrease in a certain direction in this study, although during the first eleven days tomatoes from RT treatment had higher levels than those from F treatment, while at day thirteen and onwards the inverse was seen. Similar to the TSS levels no significant differences were observed for day or treatment and no interaction was seen (Figure 22). Mandarin acidity levels, however, responded positively to storage in RT treatment and these increased considerably between day one and six by 3-fold. There was also an increase in the TA levels of mandarins from F treatment between these time points. By day eight however, TA levels of mandarins from either treatment were similar, as the acidity of mandarins from RT treatment had begun to decline after day six. Unlike round salad tomatoes, treatment was found to have significant effect on the TA levels of mandarins (p=0.010).

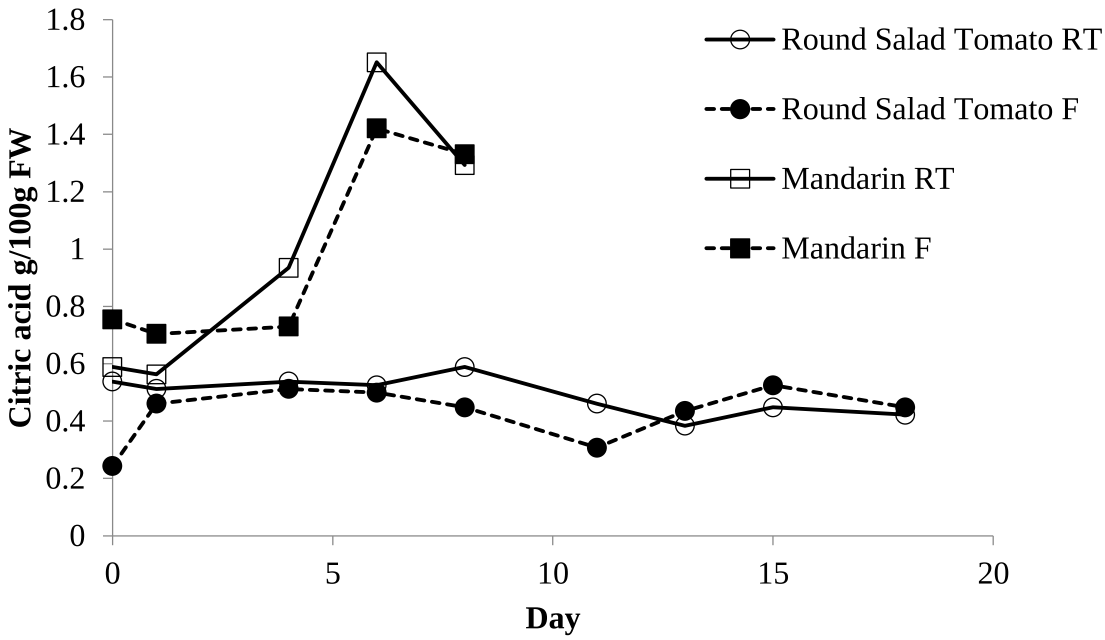

Figure 22 Titratable Acidity of Round Salad Tomatoes and Mandarins. Titratable acidity (Citric acid g/100g FW) of shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature. Treatment, day and their interaction were not found to have a significant effect on TA levels of round salad tomatoes (p=0.283, p=0.427 and p=0.589 respectively). For mandarins, day or the interaction between day and treatment were not significantly different either (p=0.467 and p=0.092 respectively)

Round salad tomatoes had slightly higher levels of pH compared with mandarins in this study, and this was similar to having lower citric acid levels than the mandarins, and the pH levels increased slightly in tomatoes from both treatments as the study progressed. However levels were higher in tomatoes from RT treatment (Figure 23), and treatment was found to have statistically significant effect on pH levels ($p<0.001$) and an interaction between day and treatment was seen ($p=0.033$). This differed from the results for mandarins where treatment ($p=0.687$), day ($p=0.387$) and their interaction ($p=0.998$) were not found to have a significant effect on pH.

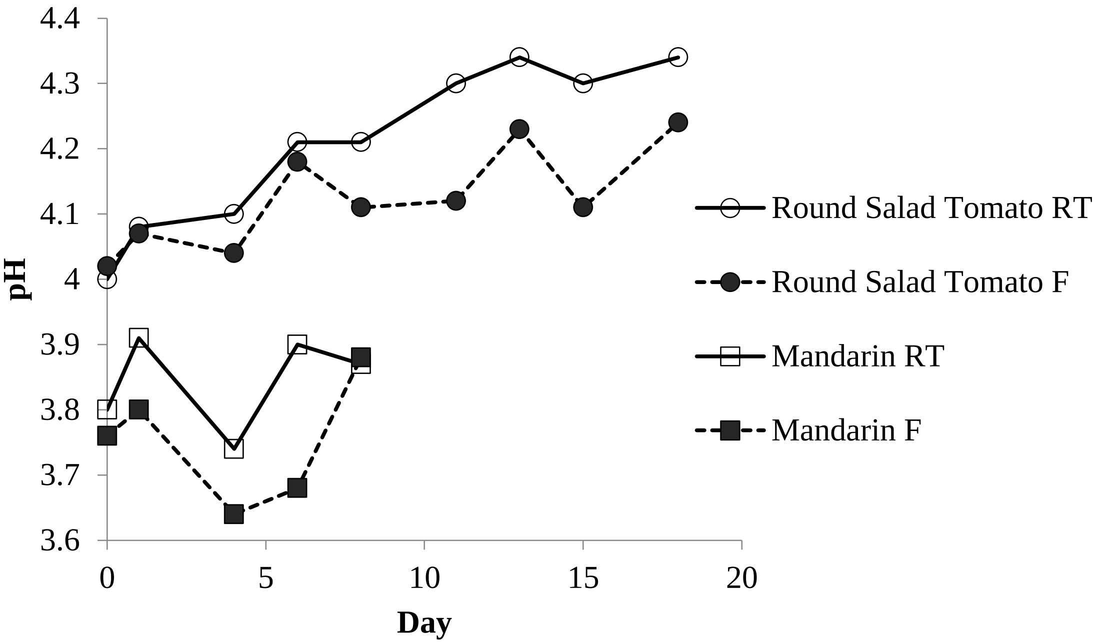

Figure 23 pH of Round Salad Tomatoes and Mandarins. Shop bought fruits were kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

Tomato quality, in terms of pH levels was positively affected by RT treatment. Little differences were seen in acidity and TSS between treatments. This was unexpected since tomato flavour is largely influenced by the balance between sweetness and sour taste, and since differences in taste were seen between treatments, difference in acidity and sweetness were also expected to be seen. However, tomato taste is also affected by aroma, so it may be that those from RT treatment were higher in levels of characteristic tomato aroma levels, and so were perceived as better in taste. For mandarins, RT treatment increased levels of TA as compared with F storage which will have made them taste sourer, and this may have been why the taste scores for mandarins began to decline between day one and eight.

2.4.5. Cherry and Plum Tomatoes

Cherry and plum tomatoes had similar responses to temperature treatment for deformation, and so in this case the results for cherry tomatoes have only been shown as a representation of both tomato types for this quality measurement. Unfortunately, plum tomato samples ran out after day four so no data is provided after this time point.

2.4.5.1 Taste

As the study progressed the taste scores decreased in cherry tomatoes, irrespective of treatment, and mostly cherry tomatoes from F treatment were scored higher than those from RT treatment (Figure 24).

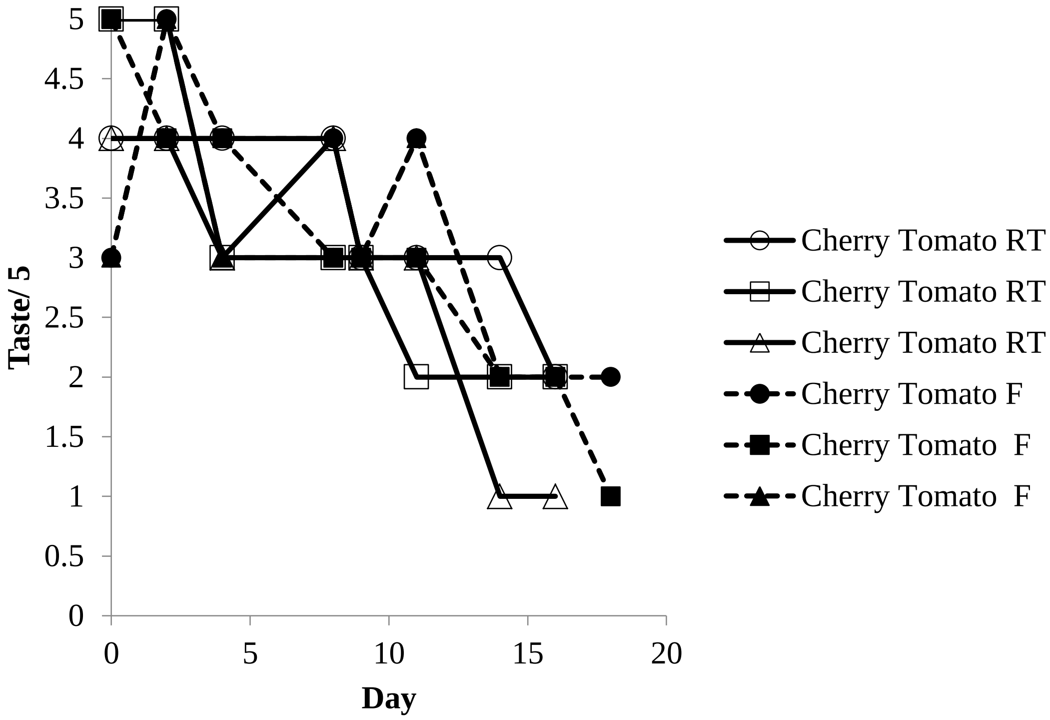

Figure 24 Taste Scores of Cherry Tomatoes. Taste score out of 5 for shop fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

For plum tomatoes, little difference was seen between treatments, and in general taste scores decreased for samples from both treatments (Figure 25). Since plum tomatoes from either treatment were not taste tested after day four, it is difficult to see differences between the taste scores and compare with the results of the cherry tomatoes.

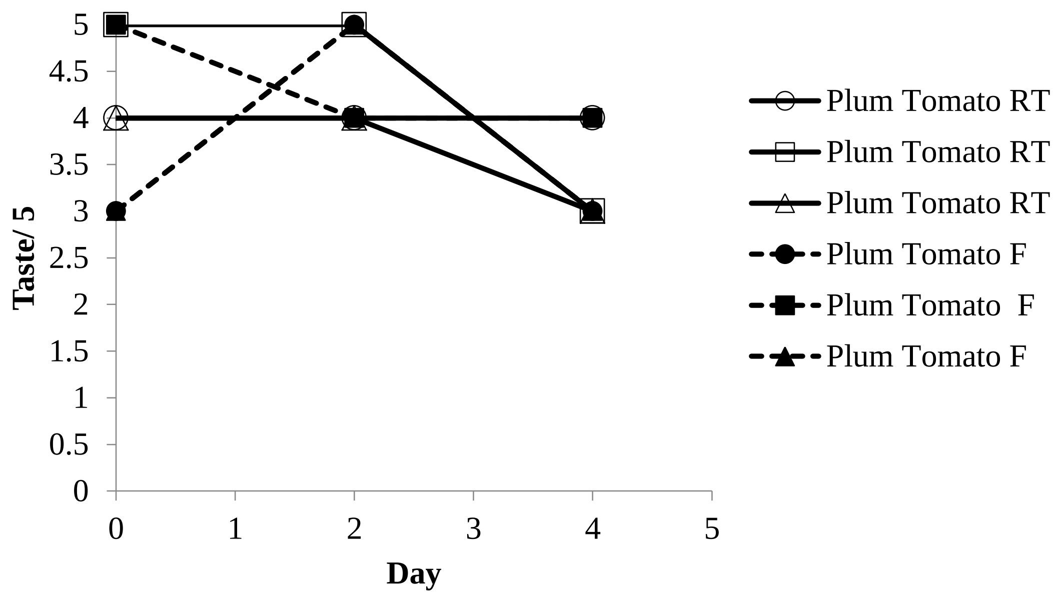

Figure 25 Taste Scores of Plum Tomatoes. Taste score out of 5 for shop fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

Cherry tomato quality in terms of taste was generally reduced by storage at RT treatment. Since plum tomatoes were only studied for four days it is difficult to conclude the effects of temperature on plum tomato taste. However, since cherry and plum tomatoes are of similar constitution, it can be assumed that plum tomatoes would respond the same to temperature treatment if they were studied for a longer period of time.

2.4.5.2. Shelf life

Cherry tomatoes from RT treatment lasted for sixteen days and those from F treatment lasted for eighteen days. Unfortunately, since the plum tomatoes ran out within four days it is unknown what the shelf life would be for these fruit types, but since they are similar to cherry tomatoes in their composition, just as described for taste, it can also be assumed that they would have similar responses in shelf life to temperature to that of the cherry tomatoes used during this study.

2.4.5.3. Firmness

The deformation values declined as the study progressed in cherry tomatoes from both treatments (Figure 26). Interestingly, tomatoes kept at RT had greater deformation values compared to those from F treatment on a number of occasions (day four, nine, fourteen, sixteen, and eighteen), and the GLM analysis showed only treatment to have a significant effect on the deformation values ($p<0.001$ for cherry tomatoes and $p=0.048$ for plum tomatoes).

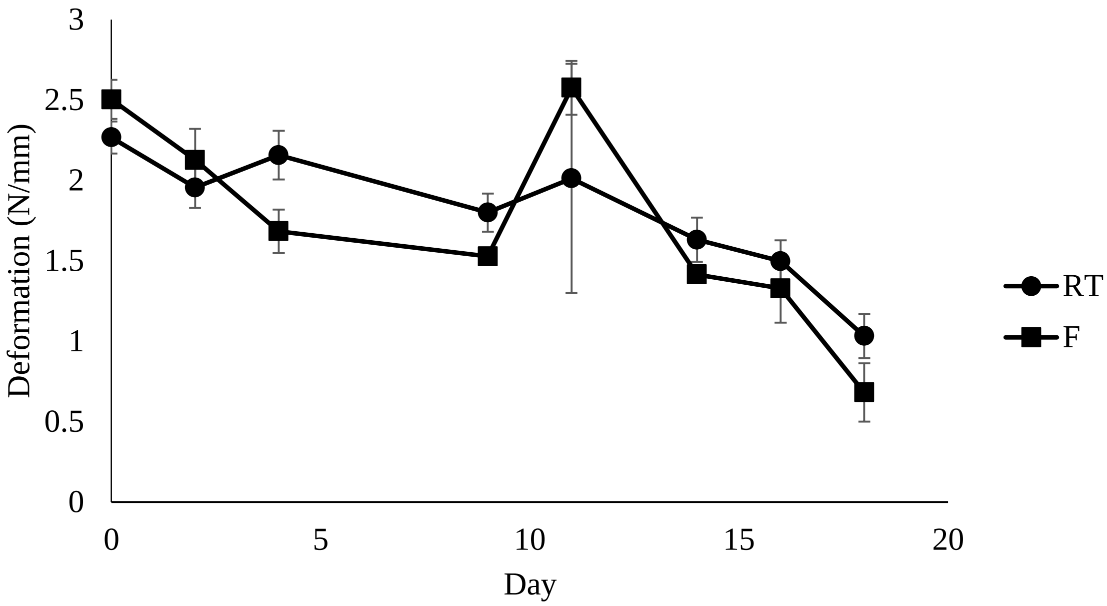

Figure 26 Deformation of Cherry Tomatoes. Mean deformation (N/mm) of shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature. Bars represent standard error

As was seen for deformation values of the cherry tomatoes, the penetration values also decreased with time in fruit from both treatments (Figure 27). Variability is seen in the penetration values, and neither RT nor F treatment produced cherry tomatoes with the greatest penetration values consistently, and by the end of the study tomatoes from both treatments had similar values. Additionally, similar to the results for cherry tomato deformation, only treatment was found to have a significant effect on cherry tomato penetration ($p<0.001$). For plum tomatoes, no statistical significance was seen amongst fruits from different treatments ($p=0.137$), although plum tomatoes kept at RT treatment did decrease in penetration values between day zero and four. Only day was found to have a significant effect on plum tomato penetration values ($p=0.001$), however an interaction between day and treatment ($p=0.004$) was seen.

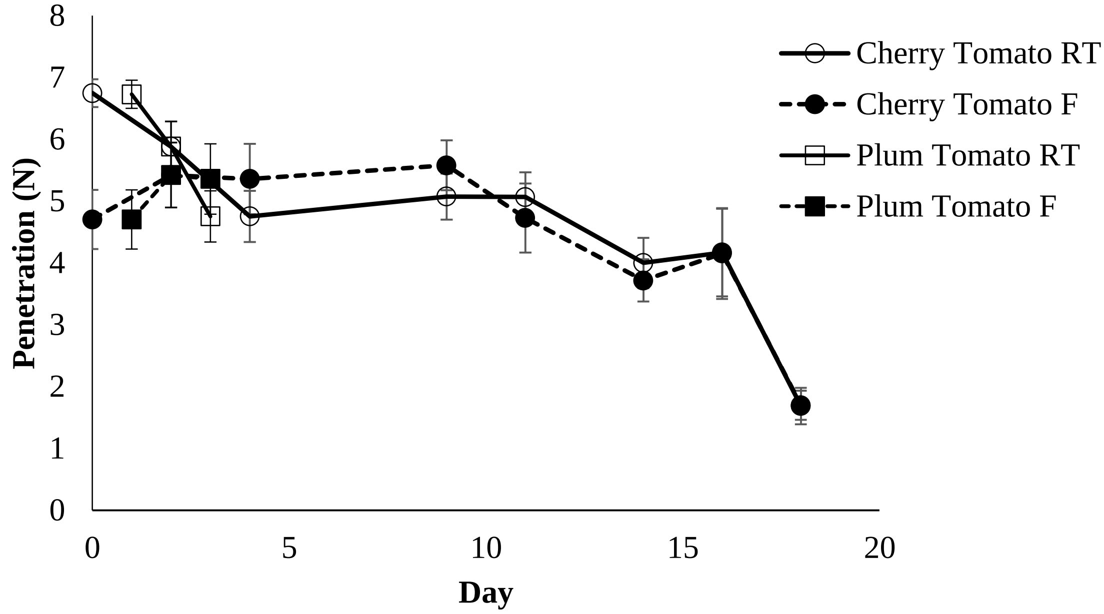

Figure 27 Firmness (Penetration) of Cherry Tomatoes and Plum Tomatoes. Mean penetration (N) of shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature. Bars represent standard error

Similar to the studies involving grapes and strawberries, the firmness method was difficult to use on cherry and plum tomatoes because of their small size. This may explain the variability in the penetration and deformation seen amongst the cherry and plum tomatoes from different treatments. However, the results did show a decline in both deformation and penetration values showing the cherry and plum tomatoes from both treatments had reduced quality in terms of firmness as the study progressed.

2.4.5.4. Chemical Constitutes: TSS, TA and pH

In general a small increase in TSS is seen as the study progressed for cherry tomatoes from RT treatment, while for tomatoes from F treatment similar TSS contents are seen by the end of the study to those at the initiation (Figure 28). Treatment was the only factor found to have a significant effect on TSS content of cherry tomatoes (p=0.027). For plum tomatoes from the different treatment TSS levels were relatively similar throughout the four day analysis period (Figure 28), and neither treatment (p=0.700), day (p=0.988) nor their interaction (p=0.781) were found to have a significant effect.

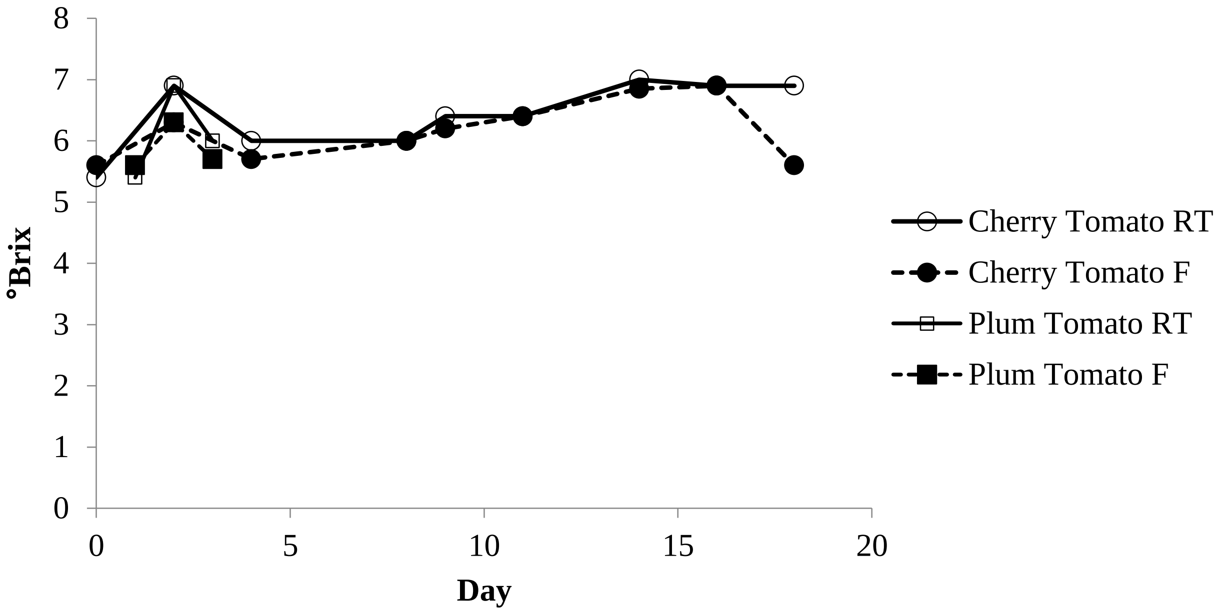

Figure 28 Total Soluble Solid Contents of Cherry Tomatoes and Plum Tomatoes. TSS values (°Brix) of shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

Both cherry and plum tomatoes had similar TA levels for the first two days of the study and interestingly by day four, cherry and plum tomatoes from RT treatments both had decreases in TA values, while those from F treatment continued to increase at this time point (Figure 29). The TA levels of cherry tomatoes from both treatments varied over time. Similar to TSS values, treatment was the only factor to have a significant effect on TA content of cherry tomatoes ($p=0.019$). Also, similarly for plum tomatoes, as was seen for TSS, treatment ($p=0.322$), day ($p=0.634$) and their interaction ($p=0.231$) were not found to have a significant effect on TA levels.

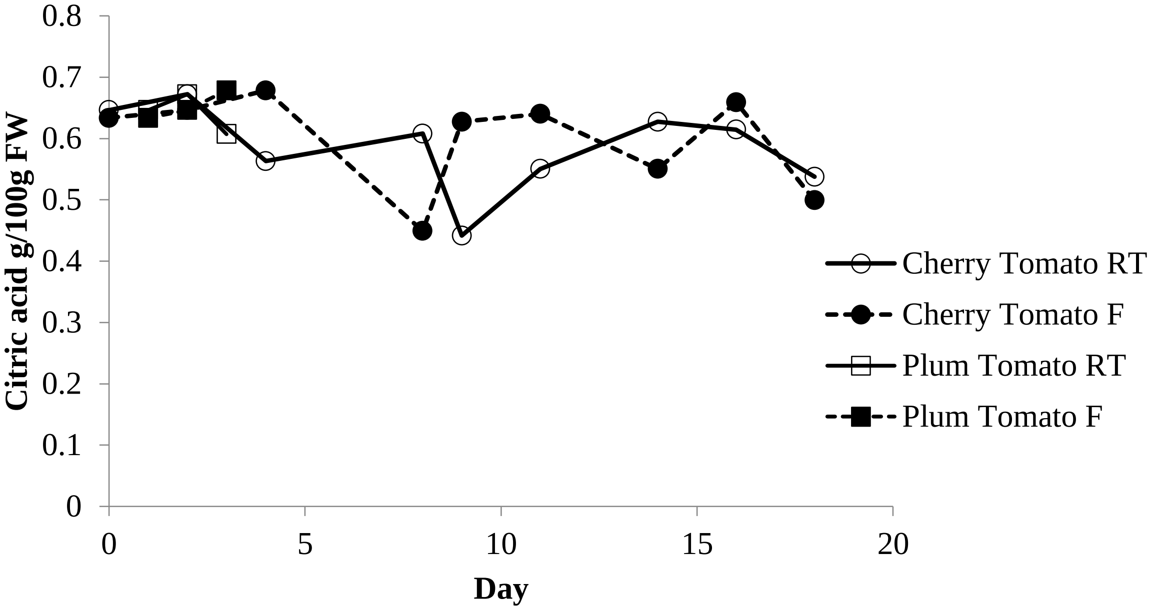

Figure 29 Titratable Acidity of Cherry Tomatoes and Plum Tomatoes. Titratable acidity (Citric acid g/100g FW) of shop bought fruits kept at either room 22˚C (RT) or refrigerator 6˚C (F) temperature.

As the study progressed the pH values of cherry and plum tomatoes from RT treatment slightly increased (Figure 30). For tomatoes from F treatment there was not such a clear rise, although by the end of the study the pH levels were higher than those at initiation for both types of tomatoes. In general, RT treatment had greater levels of pH, but by only a small amount, and treatment was only found to have a significant effect on pH levels ($p=0.006$). For plum tomatoes from F treatment, the pH values did not change during the four day study, while those from RT treatment increased between day zero and two, although did not change any further between day two and four. As was seen for TSS and TA contents, no significant differences were seen for plum tomatoes for treatment ($p=0.205$) day ($p=0.403$) or their interaction ($p=0.250$), most likely due to the too few sample dates.

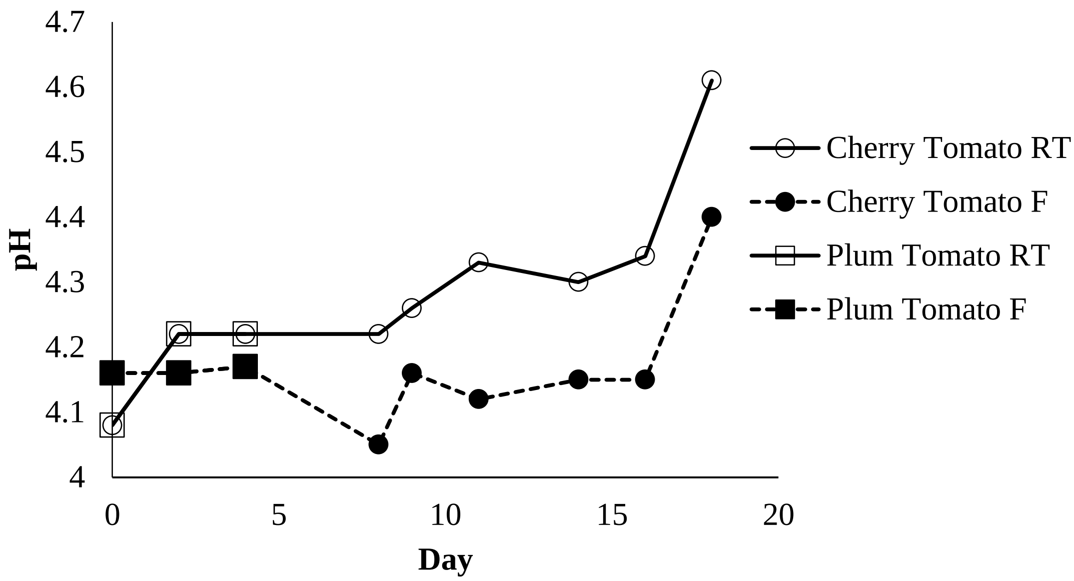

Figure 30 pH of Cherry Tomatoes and Plum Tomatoes. pH of shop bought tomatoes kept at either room 22°C (RT) or refrigerator 6°C (F) temperature.

For cherry and plum tomatoes few statistically significant differences were seen between tomatoes from different treatments, although TSS and pH values were generally higher in fruits kept at RT treatment, suggesting that RT treatment has a positive effect on plum and cherry fruit quality, but not by a particularly large amount.

2.5. Discussion

No visible signs of CI were seen in tomatoes, peaches, plums, nectarines and mandarins from any of the treatments even though they had all been through the supermarket supply chain. Moreover, fruit kept at F treatment did not appear to show any visible signs of CI either. This was surprising as the literature has implied otherwise (Hobson, 1987; Maul *et al.*, 2000; Sanchez-Ballesta *et al.*, 2003). This may have been since there was a relatively small number of fruit samples used, and therefore since most of these samples were used for analysis rather than observed for visual quality this may have been why CI was not noticed. This implies that considerably more samples should be used in the following studies to avoid this reoccurring. Although no visual signs of CI were seen, CI may have accounted for the lower scores in taste for round salad tomatoes and nectarines stored at refrigeration temperatures compared with room temperature (Hobson, 1987; Lurie *et al.*, 1997; Maul *et al.*, 2000; Farneti *et al.*, 2010).

Tomatoes kept above 13°C in RT treatment were higher in quality in terms of taste, although this was not the case for plum and cherry tomatoes, and this may be due to variation seen within tomato types, and may also be caused by differences in length of their supply chains as cherry and plum tomatoes may have been refrigerated for longer by the supermarket than the round salad tomatoes used during this study, and therefore it is difficult to directly compare between tomato types. In hindsight it would have been useful to have information on the origin of the fruits during this study and also the length of the supply chain. However, from this study there are implications that round salad would be a good fruit type to study during the pilot research.

RT treatment generally improved the taste scores of round salad tomatoes, grapes and nectarines, therefore suggesting that these fruit species have potential to be studied in the next phases of experiments. Although the taste scores during this study provided important information about the changes of taste as affected by storage temperature, the taste results are subject to bias as there was only one researcher tasting the samples. Therefore, there is a requirement for the development of a non-subjective sensory analysis on the appropriate fruit as described sequentially in Chapter 3. All the other experimental methods used during this study proved to be suitable for all fruit species that is except for the method used to measure fruit firmness which was difficult to use on the smaller or non-round fruits such as the grapes, cherry tomatoes, plum tomatoes and most noticeably strawberries. Since firmness is an important measure of fruit quality by the producer and consumer, these fruits will not be studied further during this research project.

The number of samples used needs to be increased substantially to allow for more fruit samples to be observed for visual signs of CI as described above, but also so more fruits can be observed for shelf life and left to see whether decay, mould or wrinkling occurs and at what time point, rather than being used up during quality analysis as was seen for plum tomatoes which were depleted after only four days, and also mandarins which by day 11 there were not enough samples left to cover all quality analysis and only taste analysis was performed.

The response to higher temperature of fruit quality varied with fruit type. RT treatment did improve the TSS contents of the grapes, nectarines and cherry tomatoes analysed during this study, but had no effect on the contents of the mandarin, peach, plum, round salad tomato and plum tomato fruits. TSS is an important contributor to overall consumer preference (Malundo *et al.*, 2001; Pelayo *et al.*, 2003; Wu *et al.*, 2003; Predieri *et al.*, 2005; Mahmood *et al.*, 2012; Delgado *et al.*, 2013; Shinya *et al.*, 2014). This may also explain why the taste of grapes, round salad tomatoes, and nectarines were negatively influenced by F treatment, as a reduction in TSS was also seen for these fruits from this treatment. Regarding TSS, there is potential for strawberry, grape and nectarine quality to be improved by increasing temperature, therefore there are implications that these fruit could be studied in the next phase of experiments using the same methods for chemical analysis that were employed during this study, however, due to the unsuitability of grapes and cherry tomatoes for firmness tests, they will not be studied further.

The pH levels were mainly stable throughout for all fruit types, and this was expected as pH has been reported to be unchanged during storage (Puerta-Gomez and Cisneros-Zevallos, 2011b; Giovanelli *et al.*, 2014), except for all the tomatoes analysed which had higher levels when kept at RT treatment over time. Temperature has also been shown to have little effect on the TA of fruit during storage, (Ayala-Zavalaa *et al.*, 2004; Goren *et al.*, 2010), and this was also seen during this study for most fruit types, except for mandarins and round salad tomatoes where an increase was seen in both treatments, but highest levels were in those from RT treatments. As described previously TA levels will contribute to the sugar acid balance which influences fruit taste, and since mandarins did not have increased TSS levels in tandem with increasing TA levels, this implies that increasing temperature will make mandarins more sour and give poor taste, suggesting that this fruit type will not benefit from higher temperatures and so will not be investigated any further during this research project. Since the TSS contents generally did increase in round salad tomatoes kept at RT treatment as did TA, there are implications that this fruit will be an appropriate fruit to have enhanced quality in terms of TSS and TA contents with increasing temperature, and therefore would be a good fruit to study further.

Weight loss and rate of weight loss was higher in all fruit types that were exposed to RT treatments compared with F treatment, and this is a common occurrence across fruit types (Ghaouth *et al.*, 1991; Paull, 1999; Javanmardi and Kubota, 2006). Firmness (either deformation, penetration or both) was generally maintained by F treatment in all fruit types, which was expected (Bourne, 1982; Shin *et al.*, 2007; Crisosto *et al.*, 2008), except this was not so apparent for cherry tomatoes. Since fruit such as tomatoes or nectarines have shown to benefit from warmer temperatures of RT in terms of TSS and taste, there may be temperatures higher than F treatment, but lower than RT that can improve fruit taste, while preserving fruit firmness. Round salad tomatoes were not analysed for firmness during this study, but since they are a similar size and shape to stone fruit, for which the firmness method worked well, there are implications that the firmness method are suitable.

In terms of shelf life, strawberries were the only fruit to suffer any pathogen attack and this was only seen in those from RT treatment, suggesting a reduced shelf life at RT treatment as compared with F treatment. Peaches also had very short shelf life when kept at RT treatment and were shrivelled and wrinkly and not taste tested after day three, having a shelf life that was four days shorter than those from F treatment. For all the other fruits, expect for nectarines, fruit from RT treatment were not taste tested on the final day of the taste testing in the studies as they were visibly shrivelled or soft, suggesting that RT treatment did not increase the fruits susceptibility to pathogen attack, but did allow the fruits to continue to ripen as intended. However, in hindsight, if there were more samples that could be observed as mentioned previously, then it is likely that more decay incidences would be recorded. Therefore this is something that is done in the following studies.

The results of this study demonstrate the influence of temperature on fruit quality, and show the different responses of a range of fruit types. In general F treatment retained fruit firmness and decreased weight loss, but had either negative or no effect on fruit taste. No signs of CI were seen in any of the fruit analysed, except for the taste scores of round salad tomatoes, grapes, and nectarines. It can be concluded from this study that out of the ten fruit investigated, there is potential for the quality of nectarines, red grapes, green grapes and round salad tomatoes to be improved by warmer temperatures, with round salad tomatoes being the most likely to benefit since they had the longest shelf life out of these mentioned fruit, the lowest rate of weight loss out of all the fruits when kept at either treatment, and were suitable for the experimental methods employed. Round salad tomatoes also had increased TA and TSS contents and therefore taste when kept at RT treatment, suggesting that increasing temperature can help increase round salad tomato quality, as previously documented by (Kader *et al.*, 1978).

Since the only quality differences were seen for taste and TSS and no signs of CI were seen there are implications that in the research that follows further analysis of fruit quality should be introduced, such as antioxidant levels to see if these are affected by temperature. This further implies that more samples should be used in the studies to follow by at least five times per treatment to ensure abundant sample numbers for all tests.

Conclusion

From this study it can be concluded that round salad tomatoes are an appropriate fruit to focus on in the research that follows. However, nectarines and grapes could be considered for further studies, depending on the outcome from the tomatoes. This study also showed that the methods used are suitable for the next step in this research project, however, additional methods will be used for other quality aspects, specifically shelf life measurement techniques and analysis of nutritional contents in terms of Vitamin C, carotenoid and phenolic compound accumulation. Additionally, the origin of the produce and history of storage will be recorded when applicable.

Chapter 3. Method Development Regarding Instrumental and Sensory Analysis of Tomato Firmness, and the Effects of Sample Presentation on the Sensory Perception of Tomatoes from Different Temperature Treatments

3.1. Introduction

The conclusions from Chapter 2 suggest that round salad tomato taste is positively affected by high temperatures. These types of tomatoes will therefore be the centre of the remainder of this research project.

Instrumental firmness can be analysed by deformation and penetration, while sensory analysis of firmness involves the texture perception before and during eating. Several studies have found a difficulty in finding a direction relationship between instrumental and sensory measurements of fruit firmness. For instance, it has been shown that sensory analysis is better at determining firmness of diced tomatoes than instrumental firmness measurements (Lee *et al.*, 1999). Similarly, Thybo et al., (2005) also found that sensory analysis of firmness is better for detecting only small firmness differences in tomato firmness as compared with instrumental firmness measurements, and they concluded that the combination of sensory and instrumental firmness measurements combined provided the best description of tomato firmness. Additionally, in another study, only weak correlation was found between sensory firmness perception and instrumental firmness of blueberries (Saftner *et al.*, 2008). It is therefore necessary before a large scale research project that instrumental and sensory firmness techniques are developed that can be directly related to each other.

As described previously in Chapter 2 robust sensory techniques needs to be used, rather than simple taste testing by the researcher. Sensory analysis needs to be free from bias in order to provide accurate results. The NU-Food Facility at Newcastle University has an established comparative consumer profiling method that is normally used for analysing the sensory perception of food, and this method was adapted to be suitable for the use with tomatoes by developing the correct descriptive words.

It is important that the sensory questionnaire in place is optimised, and to do this focus groups can be used. Focus group research often precede various forms of consumer research as it is useful tool to provide information on the consumers' perception of a particular product (Marlow, 1987; Chambers and Smith, 1991), and the discussions that are involved in an open environment often encourages group members to discuss thoughts and opinions that they may not normally divulge (Lindlof and Taylor, 2002; Ngapo *et al.*, 2004). Focus groups can therefore help shape following research to be best suited to that particular product, saving time and costs.

Focus groups have been successfully used in the past and have provided consistent results when repeated. This has been shown in focus groups regarding mungbean noodles where out of the five focus groups held, the participants consistently compiled similar lists of sensory descriptors (Galvez and Resurreccion, 1992). Similarly, in a more recent study it was found that out of three focus groups conducted there was agreement on the sensory characteristics of consuming pork from different breeds of pig (Meinert *et al.*, 2008). Additionally, it was also found that the results from these focus groups were supported by instrumental data such as results of firmness, colour and carbohydrate contents, suggesting that focus groups can also provide good quality qualitative data

Sample order during sensory analysis has been shown to have an effect the participants' response, and this has been demonstrated by Biswas et al., (2014) who showed that consumers consistently preferred the first product out of two products with similar sensory cues, and they showed this for both flavoured drinks and chocolate. Bearing this in mind, it is therefore crucial that sensory analysis methods use a sample order that will not cause bias.

Aims and Hypotheses

The aim of this study was to develop, test and if relevant improve the methods for assessing tomato sensory characteristics, including development of vocabulary and of instrumental techniques for assessing firmness, and testing whether participants can differentiate between tomatoes from different treatments when presented together with different samples to challenge whether the comparative consumer profiling developed during this research project is robust.

Hypotheses

- Some terms are so well recognised and relevant for tomato quality that they are suitable to describe tomato quality profiles by a panel of untrained consumers using sensory comparative profiling.
- One or more instrumental firmness measures are sufficiently sensitive to distinguish between tomatoes from temperature treatments that a consumer panel scores with significantly different firmness
- The order of which tomato samples are presented to the participants during sensory analysis has an effect on the participants' response

3.2. Materials and methods

3.2.1. Tomatoes

30 shop bought round salad tomatoes *Lycopersicon esculentum* Mill. variety Encore were used. Eight tomatoes were subjected to day zero firmness analysis to ensure all tomatoes were similar (data not shown). Following this, 11 tomatoes were moved to refrigerator temperature (F) (5±0.5°C) in a 13m^3 chiller unit, and 11 tomatoes were kept at room temperature (RT) (23±1°C) in a temperature-controlled room (16m^3) in the Agriculture Building of Newcastle University, for four days. After four days tomatoes were then sensory tested by 7 people and also subjected to instrumental firmness analysis.

3.2.2. Focus Group One

Prior to starting sensory analysis with volunteers a focus group discussion using ten staff and students of Newcastle University was held to discuss what descriptive words they as the consumer associate with tomatoes (Table 8). Volunteers were presented with shop bought tomatoes which had been sliced and a table of descriptive words was prepared and presented to the volunteers. Volunteers were asked to tick the words that they believed are the most appropriate when describing tomato quality. Participants were also encouraged to write down any relevant extra words that they did not see in the table.

Table 8 List of Sensory Descriptors Combined by the Researcher and Presented to Volunteers of a Focus Group

Sensory Descriptor	Please tick if relevant to tomatoes
Fleshy	
Juicy	
Acidic	
Sugar : acid balance	
Sweet	
Bitter	
Sour	
Salty	
Smokey	
Aromatic	
Watery	
Woody	
Off flavour	
Earthy	
Colour	
Glossy	
Flavour	
Aroma	
Pungent	
Texture	
Crunchy	
Crisp	
Soft	
Ripe	
Astringent (dry puckering mouth feel)	

From the focus group it was decided that appropriate words to use to describe tomato quality were colour, ripeness, moistness, aroma, flavour, sweetness, firmness, crunchiness and overall opinion.

3.2.3. Sensory Testing

Following this the sensory testing was done as comparative consumer profiling, using an un-trained sensory panel consisting of consumers recruited from the general population. This is the established method used at the NU-Food Facility at Newcastle University. Recruitment involved emails and posters within the university, and posters outside university advertising on a busy public road. Participants were required to read an information sheet (Figure 71 & Figure 72, Appendix A) and sign a consent form to agree they are happy with the requirements of the sensory testing before they began. Participants included staff and students not involved with the present project, as well as members of the public, and since the participant sample set was meant to represent the average UK consumer anyone was welcome to take part. However, before beginning the official questionnaire participants were asked to provide information on their age, gender, whether they smoke, if they are suffering from a cold, and if they have had anything to eat in the last hour (Figure 73, Appendix A). This was to provide information on the demographics of the volunteers but also in case any anomalous results emerged.

Each sensory descriptor was assessed on an unmarked line scale (15cm) labelled from 'None' at the left end to 'Very much' (or equivalent) at the right end of the scale (Thybo et al., 2005). For each descriptor, the panellists were asked to indicate the position of each of the four samples on the same scale (comparative profiling) (Figure 73, Appendix A). Participants were required to complete a training questionnaire prior to starting the sensory trial in which they were asked to compare 1/8 of a round salad tomato, 1/2 plum tomato and a 1/16 of beef tomato to familiarise the participant with the requirements of the questionnaire. All tomatoes were brought to room temperature prior to sensory testing, and each sample was 1/8 of a tomato.

Seven participants were involved in this study. For the first sensory analysis investigating sensory firmness each participant tested four plates of four samples with the order of samples switched between repetitions. Even though the sensory analysis was only focused on the sensorial firmness participants were still required to complete the full length questionnaire to ensure usual sensory testing conditions were in place. For the second sensory session investigating the effects of sample order, the first and third plates contained two slices of RT tomatoes, and two slices of F tomatoes, in an alternating sequence. The second plates contained only F tomatoes, and the fourth plates contained only RT tomatoes. This was done to investigate whether participants find differences between tomatoes from the same treatment if they are all presented at once on the same plate, rather than mixed with samples from different treatments.

3.2.4. Focus Group Two

Another focus group was repeated after the sensory analysis described in Chapters 3 and 5 to further enhance the sensory questionnaire used in Chapters 4 and 6. This involved a group of nine members of staff and students from Newcastle University.

To begin the session the following questions were asked:

- What do you associate with tomatoes/tomato products?
- How do you usually eat them?
- What do you like most about tomatoes?
- Why do you buy them?
- What do you wish for from a great tomato?
- Do you think a tomato stands out from other fruit/vegetables? If so why?

Volunteers were then presented with shop bought tomatoes that had been kept at either F or RT treatment for four days, been brought to room temperature, and then sliced. Volunteers were asked to taste tomato slices from both conditions and describe them considering appearance, smell, touch, taste and even noise when bitten into, describing both the positive and negatives. Volunteers had a hand out of the Glossary of Terms related to Sensory Analysis (British Standard). Volunteers were asked to come up with at least six words each for tomatoes from each treatment and write them down on their feedback sheets.

Volunteers were next presented with a list of the following sensory descriptors which had originally been used in the questionnaire:

Colour
Firmness
Ripeness
Aroma
Crunchiness
Sweetness
Moistness
Flavour
Overall opinion

Volunteers were asked to assign a range for each of these descriptors e.g. from ‘not very’ to ‘very’/ ‘poor’ to ‘excellent’, and so on, considering the current ranges that were used in the current questionnaire. They were also asked if they could think of a better way to phrase the sensory descriptor and whether they think there are any categories missing from the list.

The sensory descriptors that were used most commonly during the focus group were colour, aroma, flavour, firmness, crunchiness, moistness and sweetness (Table 9), with colour being seen as the most important.

Table 9 List of Sensory Descriptors from Focus Group Two. Volunteers in a focus group were asked to write down sensory descriptors that they associated with shop bought tomatoes that had been kept at RT (23˚C) or F (5˚C) for four days. Each participant was asked to provide at least six descriptors for each tomato.

Sensory Descriptor	Number of times associated with tomatoes by volunteers
colour	16
aroma	9
flavour	9
firmness	8
crunchiness	8
moistness	7
sweetness	6
chewiness	5
taste	4
acidity	4
juiciness	3
texture	3
ripeness	3
tough skin	2
odourless	2
freshness	2
bittersweet	1
temperature	1
soft skin	1
sour	1
persistence	1
insipid	1
mouth feel	1
salty	1
attractive	1
appealing	1

Considering there were only nine members in the focus group a large number of sensory descriptors resulted, and this was since a number of words were only used once by one participant.

From the second focus group it was found that the sensory descriptors used most frequently are those that are already used in the questionnaire, so it can be concluded that the focus group members agree with the questionnaire already in place. ‘Chewiness’ was not used even though it scored relatively highly, as this descriptor is not commonly used during sensory analysis of tomatoes (Maul *et al.*, 2000; Thybo *et al.*, 2005; Vallverdu-Queralt *et al.*, 2013). However ‘acidity’ was added as this is an important sensory descriptor of tomatoes and also because it can be related to the instrumental analysis of titratable acidity. Additionally, it was decided that colour should be ranked from ‘pink’ to ‘dark red’ rather than ‘greenish-pink to ‘dark red’ on the line scales. It can be concluded that the focus group has contributed to improving the questionnaire.

3.2.5. Instrumental Firmness Analysis

Firmness was measured as described in Chapter 2. Four tomatoes from each treatment were analysed for deformation and penetration of the whole fruit. Half tomato deformation was also investigated and tomatoes were cut in half by running a knife from the top of the tomato where the calyx was to the blossom end. Two positions were used; position one involved tomato halves with the internal flesh and seeds facing up, and position two used the skin side of the tomato inverted. Both positions were tested twice for each half of the tomato. Tomatoes halves were then cut in half again giving tomato quarters. The seeds and internal flesh were removed and penetration into the flesh of a fruit piece was analysed, and the tomato piece was penetrated three times, and in three different places.

3.3. Statistical Analysis

One way analysis of variance (ANOVA) was used to compare the sensory and instrumental firmness results, using a p-value of less than 0.05 as a significant difference. To investigate whether sample order had an effect on the sensory outcome the sensory results for each treatment were compared when they had been presented to the participants mixed or alone. ANOVA was also used for these data analysing the results for RT and F independently.

3.4. Results

3.4.1. Sensory

F tomatoes were seen as 20% crunchier than RT tomatoes by the participants (Figure 31, Table 10). However, RT tomatoes were only scored as 7% greater in sensorial firmness than tomatoes from F treatments, and this was not seen as significantly different.

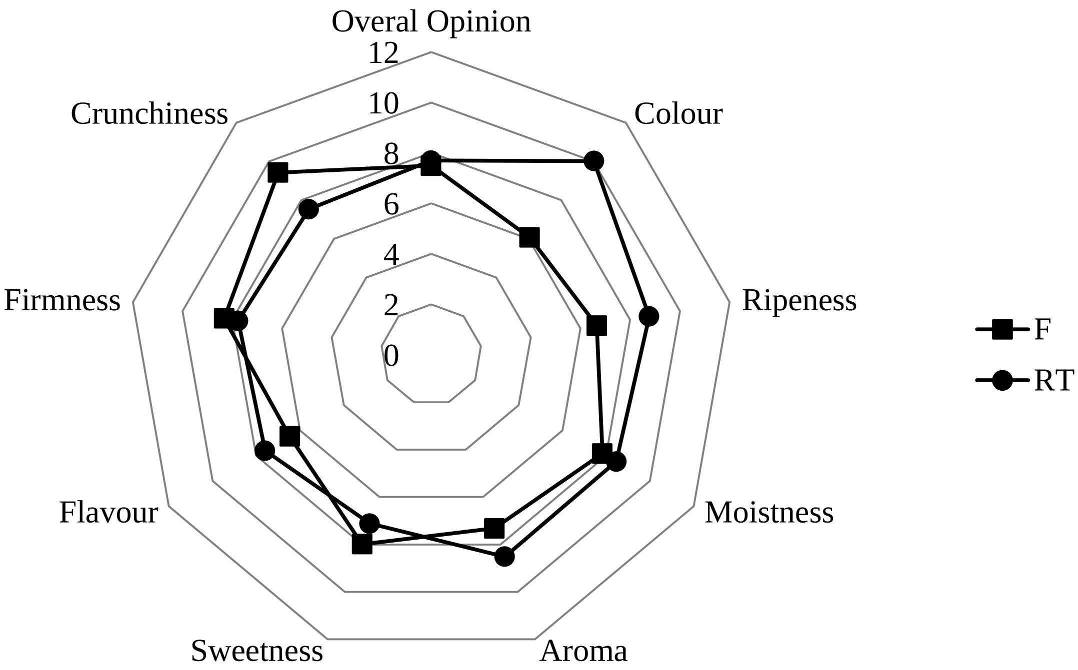

Figure 31 Mean Sensory Scores for Tomatoes. Spider plot showing sensory scores of shop bought tomatoes from different treatments. Tomatoes were either kept at 23°C (RT) or 5°C (F) for four days. Standard error of the mean (SEM) for each sensory category ranged from 0.37 to 0.54 with an average of 0.44.

Out of the other sensory categories colour, ripeness and aroma were found to be statistically higher in tomatoes from RT treatment compared with those from F treatment (Table 10).

Table 10 Probabilities for Effects of Post-sale Temperature on the Mean Sensory Scores for Different Characteristics of Tomatoes. Shop bought tomatoes were kept at either RT (23˚C) or F (5˚C) for four days. Data was analysed by ANOVA.

Sensory Category								
Overall Opinion	**Colour**	**Ripeness**	**Moistness**	**Aroma**	**Sweetness**	**Flavour**	**Firmness**	**Crunchiness**
Probability								
0.798	<0.001	0.001	0.304	0.030	0.168	0.098	0.486	0.001

3.4.2. Instrumental Firmness Analysis

Tomatoes from F treatment had greater whole fruit deformation by 23% ($p<0.001$), half fruit deformation by 21% ($p=0.002$) (Figure 32) and whole fruit penetration by 22% ($p=0.002$) (Figure 33) than RT tomatoes. A difference of only 0.8% was observed between the quarter fruit piece penetration scores of tomatoes from different treatments ($p=0.510$) (Figure 33)

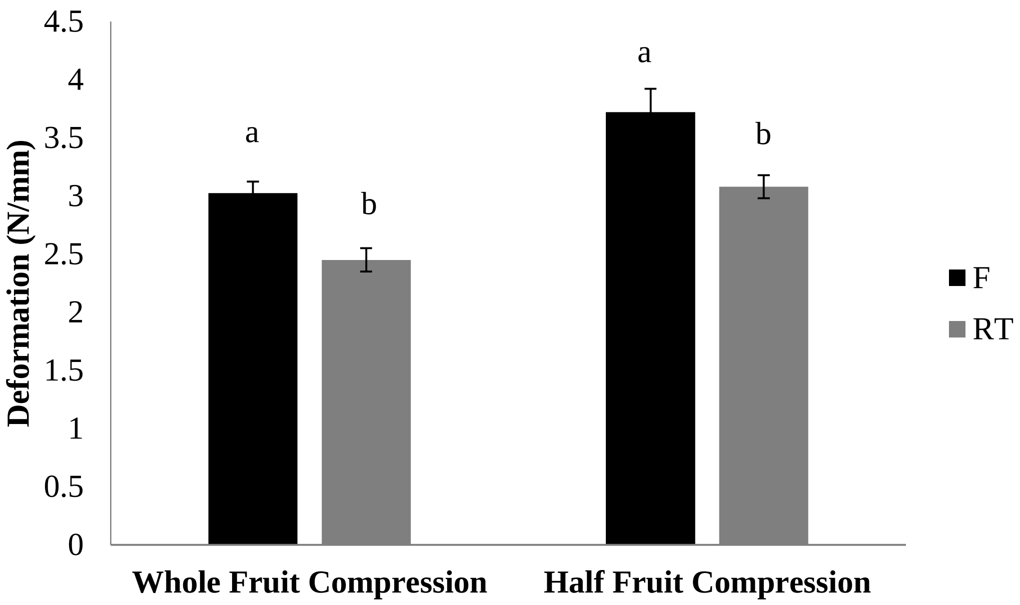

Figure 32 Mean Tomatoes Firmness (Compression N/mm). Whole fruit and half fruit compression of shop bought tomatoes kept at 23°C (RT) or 5°C (F) for four days. Bars represent standard error and different letters show significant difference (ANOVA).

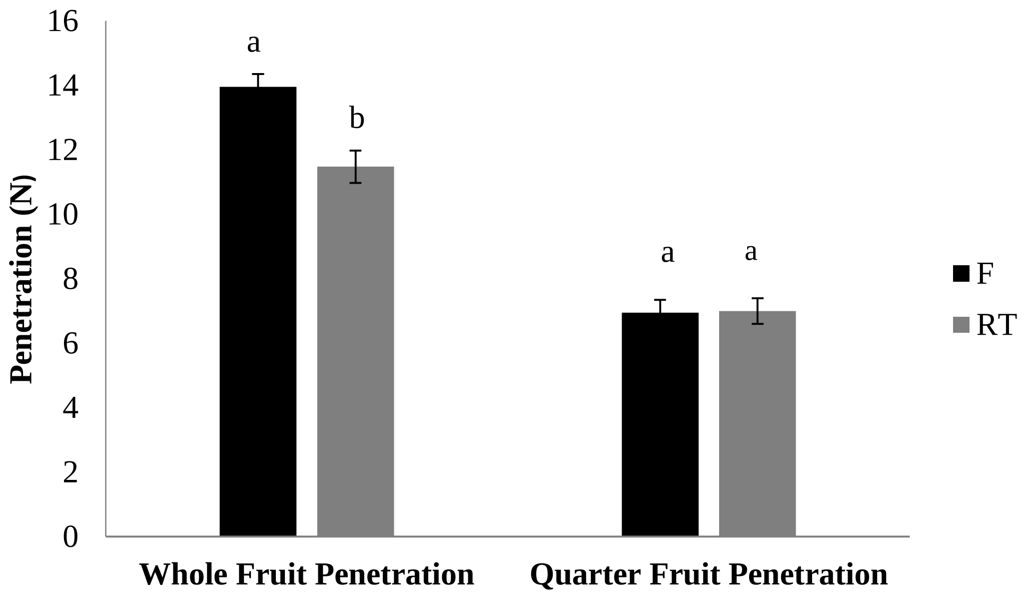

Figure 33 Mean Tomato Firmness (Penetration). Force required for penetration (N) of whole and quarter fruit of shop bought tomatoes that had been kept at 23°C (RT) or 5°C (F) for four days. Bars represent standard error and different letters show significant difference (ANOVA).

3.4.3. Differences between treatments

When tomatoes were presented to participants in a mixed order the scores for sensory categories colour, ripeness and aroma were found to have a significant difference between treatments ($p<0.001$, $p=0.004$ and $p=0.012$ respectively) (Figure 34). However, when tomatoes were presented to participants in a plate containing only tomato samples from the same treatment, only colour and crunchiness were found to have significant differences between treatments ($p=0.006$ and $p=0.005$ respectively) (Figure 35). It was noticed that only small differences were seen between tomatoes from the same treatment when presented together (data not shown). When tomatoes were presented in a mixed order RT tomatoes were scored higher than F tomatoes for colour, ripeness and aroma by 114%, 41% and 25% respectively, while when tomatoes were presented only with samples from the same treatment participants found RT tomatoes to be 39% greater in colour and 39% lower in crunchiness. The large difference between the colour values of samples presented in a mixed order will have been since there was a colour comparison that could directly be made during analysis of mixed samples.

The standard deviation for the results for each sensory category between treatments was similar for when samples were present in a mixed order and when samples were presented only with other samples from the same treatment (mean standard deviation 3.02 for both RT-mixed and F-mixed *versus* 2.97 for F-only, and 2.89 for RT-only). Colour was the only sensory category that was scored significantly different between treatments during both sample orders, and when tomatoes were presented in a mixed order, lower standard deviation was seen compared to when samples were presented only with other samples from the same treatment (standard deviation 2.57 for RT-mixed and 2.05 for F-mixed *versus* 2.61 for RT-only and 2.94 for F-only). Since more statistically significant differences were seen for sensory categories between treatments, and while standard deviations were generally similar or lower, this suggests mixed presentation of samples is better for detecting differences between tomato samples than when samples from the same treatment are only presented together.

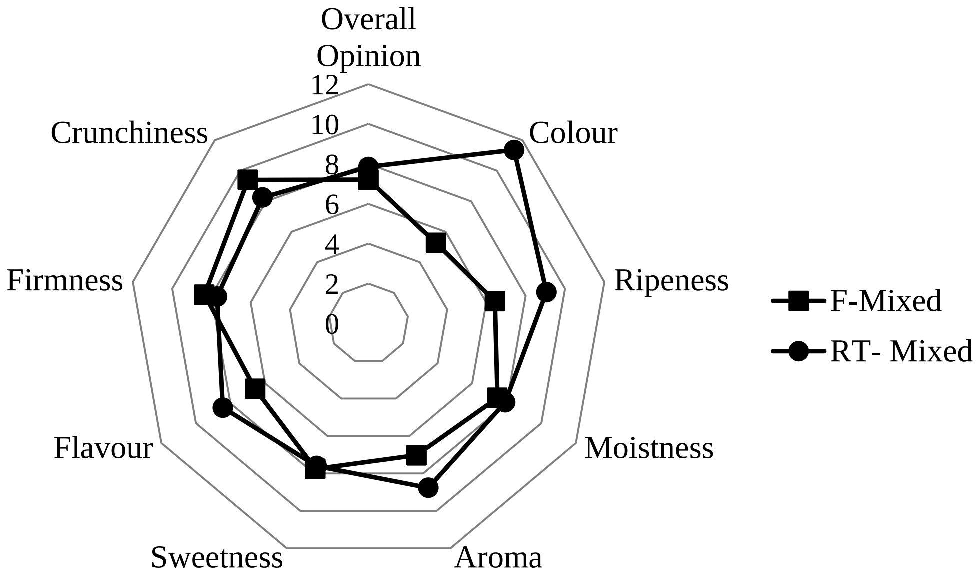

Figure 34 Sensory Scores for Tomatoes. Spider plot showing mean sensory scores awarded by participants for shop bought tomatoes from 5°C (F) treatment or from 23°C (RT) treatment that were presented on a plate to the participant in a mixed sample order. Standard error of the mean (SEM) for each sensory category ranged from 0.29 to 0.81 with an average of 0.63.

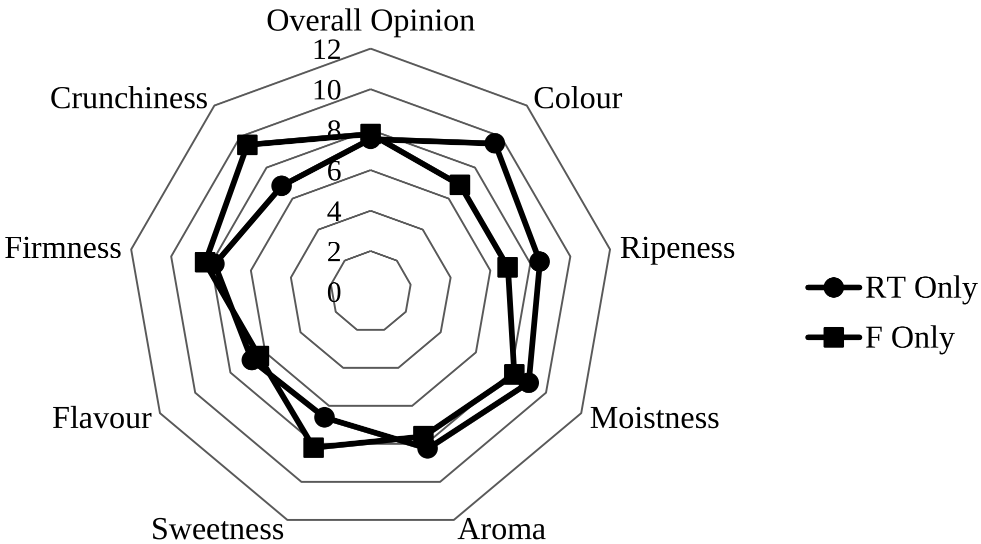

Figure 35 Sensory Scores for Tomatoes. Spider plot showing mean sensory scores awarded by participants for shop bought tomatoes from 5°C (F) treatment or from 23°C (RT) treatment that were presented on a plate to the participant with only slices of tomatoes from the same treatment. Standard error of the mean (SEM) ranged from 0.40 to 0.77 with an average of 0.61.

3.5. Discussion

The sensory descriptors derived from the first focus group were suitable for the tomato quality profiles by a panel of untrained consumers using sensory comparative profiling, and consumers found significant differences between colour, ripeness, aroma and crunchiness. The comparative consumer profiling used in this research provided similar sensitivity as in comparable studies using trained panels (Varela and Ares, 2012; Vidal *et al.*, 2014), demonstrating that this method is suitable for research to improve sensory properties of foods. It is well known that trained panels give highly detailed and robust results (Moussaoui and Varela, 2010), however, consumer profiling provides a less expensive and less time consuming alternative which gives a detailed insight into the consumer perception of food products, while also removing the effects of bias that occurs with trained panels from the influence of the trainer (Varela and Ares, 2012).

This research aimed to improve the sensory and instrumental firmness methods so that they have a directly proportional relationship. It can be concluded that whole fruit deformation and penetration, and half fruit deformation can be positively correlated with sensory crunchiness. However, even with the three positions used for quarter fruit penetration, there is no accordance with the sensory results, and this method is not used in future research. There is accordance between the sensory results for firmness and the instrumental results for whole fruit penetration and deformation, and half fruit deformation. However, no accordance was seen between the sensory results for crunchiness and the instrumental firmness data. This may have been due to the small number of participants involved in this study (seven), therefore suggesting that in following research a much larger number of participants should be used to provide a larger number of responses. This may also help differences to be seen between tomatoes from different treatments for more sensory categories.

More significant differences were seen when participants were presented with mixed sample order rather than when samples were presented with other samples from the same treatment. It can therefore be concluded that the mixed sample order design will be used during subsequent studies in this research project.

Conclusion

From this study it can be concluded that the sensory descriptors colour, ripeness, aroma, moistness, sweetness, acidity, flavour, firmness, crunchiness and overall opinion are suitable to use in a questionnaire during the comparative consumer profiling of tomatoes. Whole and half fruit deformation and whole fruit penetration are suitable for the detection of instrumental firmness differences that the participants also perceived from a sensory perspective. It can also be concluded that the order of sample presentation has an effect on the participant response during sensory analysis and a mixed sample order was seen as preferable and will be used in the rest of the research project.

Chapter 4. Investigating the Effects of Blue Filtered Lighting and Participant Age on the Sensory Perception of Tomatoes from Different Temperature Treatments

4.1. Introduction

Consumer choice is affected by the visual appearance of fresh produce, and colour is a prevailing factor that influences the consumers' perception of quality (Christensen, 1983; Calvo *et al.*, 2001). The effects of lighting and colour on consumer preference have been investigated. Colour constancy is the ability of the human eye to perceive the colour of an object as stable under changing illumination. A study by Pearce et al., (2014) showed that discrimination of changes in illumination is poorest for bluer illumination which resembles daylight, suggesting that colour constancy is best at blue daylight illumination. In a different study Oberfeld et al., (2009) found that after comparing white wine under white, blue, green or red fluorescent lamps, consumers preferred white wine under blue and red light, and green lighting lessened general liking. Additionally, blue and red light made the wine appear more valuable, and consumers gave a higher maximum buying price for the wine when it was analysed under these lights. Both these studies suggest that blue illumination has an effect on consumer perception, and that supermarkets may be able to improve the consumer opinion of produce, and therefore increase purchasing by improving illumination.

Research has shown that age can have an effect on the perception of the taste of food and drink, and that with age there is a preference for stronger tastes. This was shown in participants aged 60-75 years of age where tastants for salty, sweet, sour and bitter that had either been dissolved in water or product (ice tea, chocolate drink, mayonnaise, tomato soup and bouillon stock) were perceived as less intense in comparison to a participant group aged 19-33 years old (Mojet *et al.*, 2003), suggesting that sensory analysis is sensitive to the age of the participants involved in a sensory study.

These above studies all show that there are implications that blue illumination and age of the participant can have effects on the sensory opinion of food and drink, and since there has been a robust sensory evaluation framework involving temperature treatment developed in Chapter 3, it is possible to investigate theses effects on the consumer opinion of tomatoes from different temperature treatments.

Aims and Hypotheses

The aim of this study was to see whether there is perceptual difference between light blue filtered lighting and unfiltered lighting on the sensory outcome of tomatoes (most importantly colour), after shop bought tomatoes were kept at either F or RT for four days. This research study also aimed to investigate if the age of the participants in a sensory trial has an effect on all aspects of the sensory perception of tomatoes.

Hypotheses

- There is a difference in sensory perception in one or more sensory attribute when tomato samples are tested under blue light filter compared with unfiltered light.
- Blue light filter affects the tomato colour perception compared with unfiltered light.
- Participants can differentiate between tomatoes from refrigerator (5˚C) or room temperature (23˚C) treatment in at least one sensory attribute.
- There is a difference in tomato sensory perception of participants aged between 18-35 years of age compared with those aged 45 and older.

4.2. Materials and Methods

4.2.1. Tomatoes

Twelve packs of 500g shop bought tomatoes were kept at F or RT for four days. After four days tomatoes were analysed for sensory quality. Tomatoes were kept at different temperature treatments even though the study aimed to investigate the effect of blue light filter and participant age on sensory perception as this was the established sensory framework for this research project.

4.2.2. Sensory Testing

Sensory testing was as described in Chapter 3 using a mixed sample order, however booths 1-5 had a light blue filter over the light (Full C. T. Blue 201, LEE Filter), which converts tungsten 3200K to photographic daylight 5700 Kelvin (K), and booths 6-10 were left as normal. The blue filter made the room appear slightly bluer compared with the room with the unfiltered light and provided lighting which is more similar to that of natural daylight than the normal white lights.

Two participant groups were used to compare sensory perception. Group one consisted of 20 undergraduate students from Newcastle University and the age range was 18-35 years of age. Group two consisted of 22 members of the Newcastle University Alumni Association and were aged 45 years and above. Half of each participant grouped analysed the samples under the blue light filter, and the other half analysed the samples under normal light. The different age groups analysed different samples on independent days more than one month apart.

4.3. Statistical Analysis

General Linear Model (GLM) was used to show the interaction between temperature treatment and light condition for each age group, and to compare the effect of age group when the data is combined, using a p-value of less than 0.05 to show significant difference.

4.4. Results

4.4.1. Age range 18-35

The sensory data for tomatoes from different temperature treatments and lighting conditions were generally similar for most sensory categories (Figure 36). However, tomatoes that were kept at room temperature generally had slightly higher results for all sensory categories except firmness, crunchiness and acidity than those that were refrigerated, regardless of the lighting condition. One sensory category that stood out from the rest was colour. For the tomatoes from RT treatment, this was 37% higher than the results for the rest of the sensory categories ($p<0.001$) and seemed to distort the results on the spider plot stopping them from appearing circular. However, light filter did not have a statistically significant effect on the participants' perception of colour ($p=0.113$).

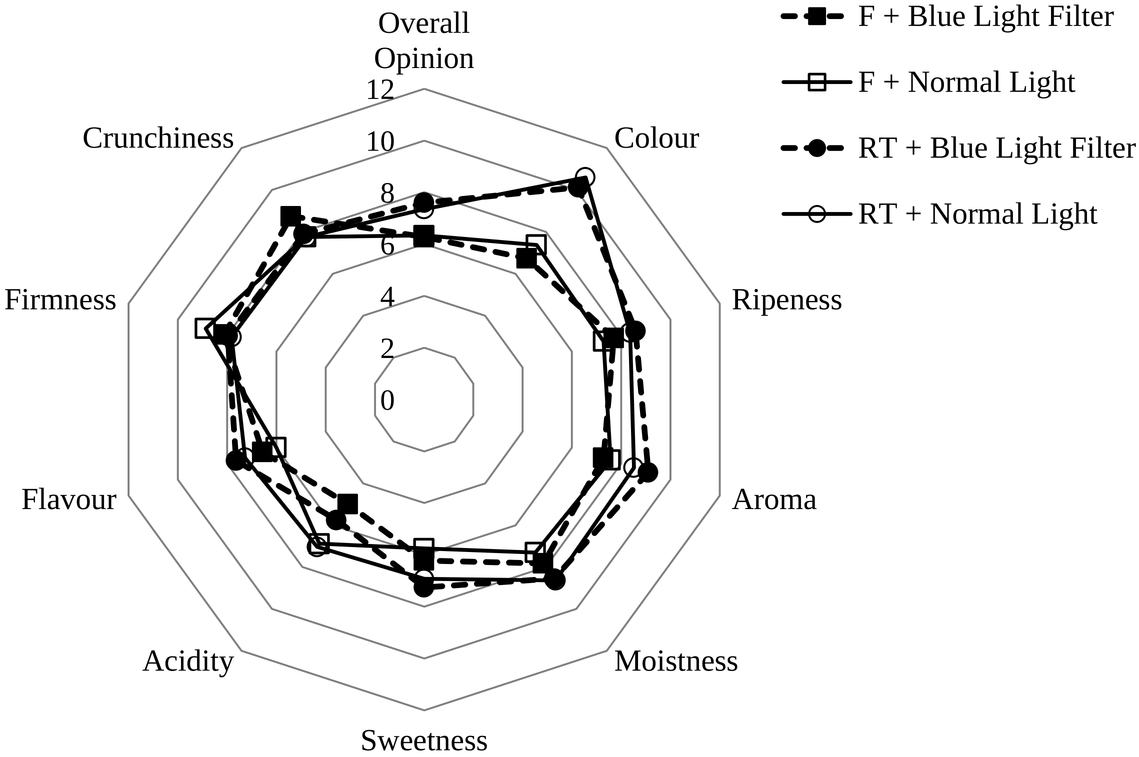

Figure 36 Spider Plot Showing Mean Sensory Scores for Tomatoes Analysed under Different Light Filters by Participants Aged 18-35 Years. Tomatoes were kept at F (5˚C) and analysed under blue light filter (F + Blue Light Filter) or under normal light (F + Normal Light), or kept at RT (23˚C) and analysed under blue light filter (RT + Blue Light Filter) or normal light (RT + Normal Light). Standard error of the mean (SEM) for each sensory category ranged from 0.28 to 0.49 with an average of 0.40.

The results showed lighting filter had a significant effect on sensory outcome, but this was only for acidity ($p<0.001$). From the spider plot this can be clearly seen as there is a drop in results for both F + Blue Light Filter and RT + Blue Light Filter, and tomatoes analysed under normal lighting were seen as more acidic with tomatoes from RT + Normal Light scored by the participants as the most acidic, which was 22% higher in tomatoes from RT + Blue Light Filter. 38% difference was seen between the scores for acidity of tomatoes from F + Blue Light Filter and F + Normal Light.

In general, between RT + Blue Light Filter and RT + Normal Light less than 8% difference was seen for all sensory categories (except acidity), most noticeably only 1% difference between scores for moistness.

RT treatment produced tomatoes that were statistically higher in sensory results in all categories (Table 11), except acidity, firmness and crunchiness where no significant differences were seen amongst treatments ($p=0.292$, $p=0.145$ and $p=0.275$ respectively). No statistical interaction was seen between light filter and treatment for any of the sensory categories.

Table 11 Probability for the Mean Sensory Scores of Tomatoes Analysed Under Different Light Filters. Tomatoes had been kept at F (5˚C) and analysed under blue light (F + Blue Light Filter) or under normal light (F + Normal Light), or kept at RT (23˚C) and analysed under blue light (RT + Blue Light Filter) or normal light (RT + Normal Light) by participants aged 18-35. Data was analysed by GLM.

	Probability									
	Sensory Category									
Source of Variation	**Overall Opinion**	**Colour**	**Ripeness**	**Moistness**	**Aroma**	**Sweetness**	**Flavour**	**Acidity**	**Firmness**	**Crunchiness**
Light Filter	0.841	0.113	0.369	0.540	0.672	0.317	0.295	<0.001	0.466	0.146
Treatment	0.011	<0.001	0.006	0.004	<0.001	0.006	0.008	0.292	0.145	0.275
Light Filter x Treatment	0.737	0.808	0.786	0.396	0.215	0.864	0.818	0.475	0.271	0.291

4.4.2. Age range 45+

The sensory data for tomatoes from different temperature treatments and lighting conditions were similar for sensory categories moistness, aroma, sweetness, acidity and firmness (Figure 37). Similar to the study involving participants in the age range 18-35, colour stood out from the rest on the spider plot, and the participants scored tomatoes from RT + Blue Light Filter and RT + Normal Light as 27% and 39% more red than F + Blue Light Filter and F + Normal Light.

As was seen for the 18-35 age group, filter was also found to have no statistically significant effect on the perception of colour in the 45+ participant group (p=0.973). Additionally, no significant effects were seen for light filter for any of the sensory categories (Table 12), and this can be clearly seen from the spider plot as results for either light treatment are grouped with respect to the temperature treatment.

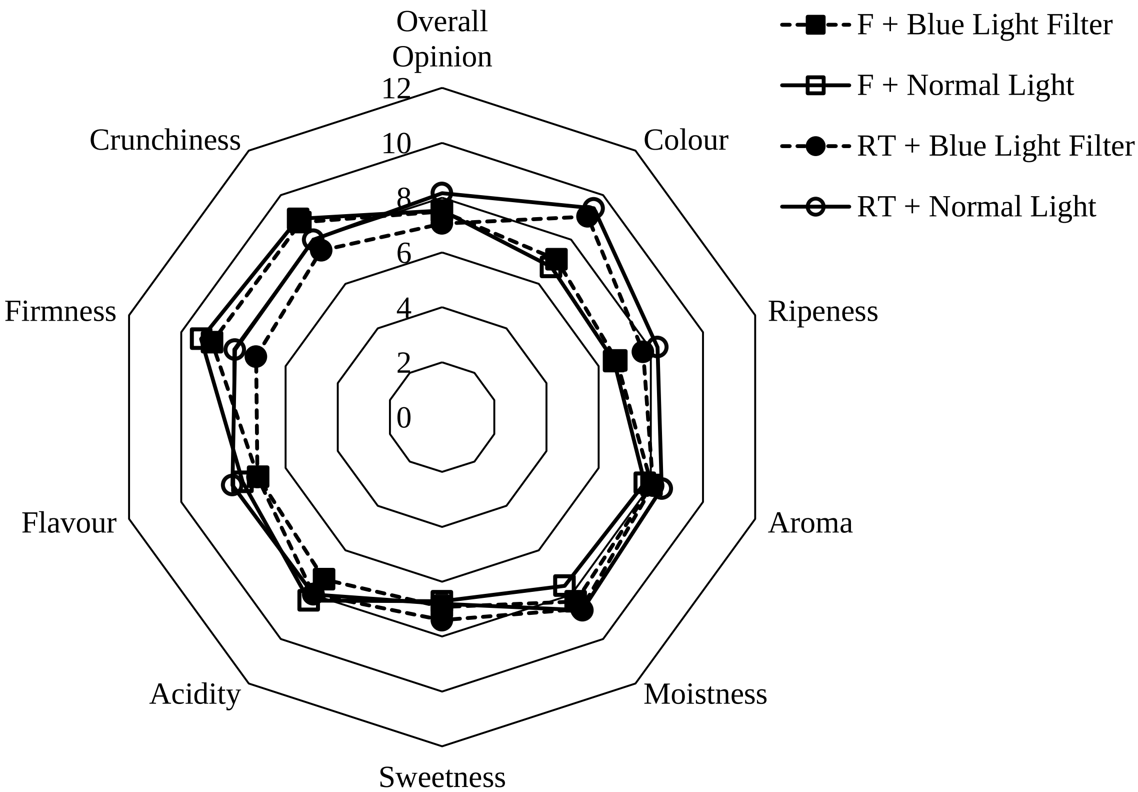

Figure 37 Spider Plot Showing Mean Sensory Scores for Tomatoes Analysed Under Different Light Filters by Participants Aged 45+ Years. Tomatoes were kept at F (5˚C) and analysed under blue light filter (F + Blue Light Filter) or under normal light (F + Normal Light), or kept at RT (23˚C) and analysed under blue light (RT + Blue Light Filter) or normal light (RT + Normal Light). Standard error of the mean (SEM) for each sensory category ranged from 0.34 to 0.60 with an average of 0.47.

Table 12 Probability for the Mean Sensory Scores of Tomatoes Analysed Under Different Light Filters. Tomatoes had been kept at F (5˚C) and analysed under blue light (F + Blue Light) or under normal light (F + Normal Light), or kept at RT (23˚C) and analysed under blue light (RT + Blue Light) or normal light (RT + Normal Light) by participants aged 45+. Data was analysed by GLM.

	Probability									
	Sensory Category									
Source of Variation	**Overall Opinion**	**Colour**	**Ripeness**	**Moistness**	**Aroma**	**Sweetness**	**Flavour**	**Acidity**	**Firmness**	**Crunchiness**
Light Filter	0.242	0.973	0.609	0.454	0.941	0.349	0.124	0.287	0.229	0.514
Treatment	0.844	<0.001	0.003	0.093	0.383	0.507	0.686	0.666	0.004	0.024
Light Filter x Treatment	0.263	0.505	0.478	0.374	0.462	0.643	0.714	0.302	0.700	0.733

Unlike for the results for sensory analysis using participants aged 18-35, treatment was not found to have a significant effect on the majority of the sensory categories for the group aged 45+ and only colour, ripeness, firmness and crunchiness were found to be significantly affected. RT treatment produced tomatoes with statistically higher colour and ripeness by 33% and 20% respectively ($p<0.001$ and $p=0.003$), while F treatment produced tomatoes that were scored significantly higher in firmness and crunchiness than those from RT treatment by 20% and 14% respectively ($p=0.004$ and $p=0.024$). This is a key difference compared with the results for the participants aged 18-35 where no significant difference in the firmness and crunchiness was perceived in tomatoes from different temperature treatments.

Similar to the results for the sensory analysis involving participants aged 18-35, no statistical interaction was seen between light filter and treatment (Table 12). For sensory categories aroma, colour, crunchiness, ripeness and sweetness ≤9% difference was seen between tomatoes from RT + Blue Light and RT + Normal Light, and less than 1% difference was seen between the scores for moistness and acidity, which is the exact same proportion that was found for moistness scores of tomatoes from RT + Blue Light Filter and RT + Normal Light by participants aged 18-35 years

Less than 13% difference was seen between F + Blue Light Filter and F + Normal light for all sensory categories. The discrepancies for the sensory categories crunchiness, ripeness and overall opinion were very small (<2%), with overall opinion only having 0.3% difference between scores.

4.4.3. Age Groups Combined

None of the sensory categories except colour, ripeness and acidity were found to be significantly affected by age group ($p=0.038$, $p=0.013$ and $p<0.001$ respectively) (Table 13). For colour and ripeness, participants from the 18-35 age group gave higher scores to the tomatoes by 8% and 10% respectively. However, for acidity, it was participants from 45+ age group that scored tomatoes as 29% higher in acidity. Light filter and age group were only found to have a statistically significant interaction for flavour ($p=0.049$), while no interactions were found between any of the sensory categories for age group and treatment (Table 13).

Table 13 Probability for the Mean Sensory Scores of Tomatoes Analysed Under Different Light Filters. Tomatoes had been kept at F (5˚C) and analysed under blue light filter (F + Blue Light Filter) or under normal light (F + Normal Light), or kept at RT (23˚C) and analysed under blue light filter (RT + Blue Light Filter) or normal light (RT + Normal Light) by participants aged 18-35 or 45+. Data was analysed by GLM.

	Sensory Category									
	Overall Opinion	**Colour**	**Ripeness**	**Moistness**	**Aroma**	**Sweetness**	**Flavour**	**Acidity**	**Firmness**	**Crunchiness**
Source of Variation	**Probability**									
Age Group	0.080	0.038	0.013	0.450	0.994	0.189	0.072	<0.001	0.788	0.383
Light Filter x Age Group	0.391	0.389	0.349	0.868	0.515	0.993	0.049	0.151	0.620	0.098
Treatment x Age Group	0.081	0.051	0.521	0.726	0.066	0.194	0.095	0.697	0.219	0.297

4.5. Discussion

Generally, no significant difference was seen in the sensory perceptions for tomatoes under different light filters for both groups. However, for the participant group aged 18-35 years unfiltered light produced tomatoes that were perceived as more acidic by the participants, and this may have been due to preconceived ideas of the participants in this age group and they may have associated tomatoes analysed under normal light with being higher in acidity than those analysed under blue light filter. This was not seen in the group aged 45+ and is unlike the results of Stommel et al., (2005) who investigated the effects of red light versus white light, and found that consumers did not perceive differences in acidity/sourness of tomatoes viewed under different illumination conditions. Nevertheless, participants were still able to differentiate between the majority of other sensory categories for tomatoes from different temperature treatments, and RT treatment was preferred over F treatment.

In both age groups colour was seen as higher in tomatoes from RT treatment, which was as expected as these tomatoes were riper. Differences were not seen between the colour of the tomato samples under different lighting conditions, suggesting that blue light filter does not affect the colour perception of consumers during this study.

The colour temperature of a light refers to the hue of a light source. Colour temperatures over 5000 K are referred to as cool colours (white to blue), while lower colour temperatures (2700–3000 K) are known as warm colours (yellow to red) (CIE, 1932). The blue filter used during this study will have created an environment within the booth of cooler colour temperatures than the unfiltered light. Although, the blue filter did not have an effect on the perception of tomatoes, there is a possibility that warmer colour illuminations may give a performance difference as was shown by Masuda and Nascimento (2013) who found that consumers preferred meat, fruit, vegetables and fish in commercial food counters viewed under warmer illuminations of 4410K compared to 6040K. This would therefore be the next step of investigation using illumination and may help guide supermarkets, shops and restaurants in their choice of lighting and its effects on consumer preference of tomatoes. However, from this study it can be concluded that normal lighting can be used for sensory analysis of tomatoes during this research project.

Unlike the 45+ age group, the 18-35 year olds did not perceive tomatoes from F treatment to be more firm or crunchy, which was surprising. Since this study only aimed to investigate the effects of light and age on sensory results instrumental firmness was not measured. However, it is therefore difficult to know whether treatment did have a significant effect on tomato firmness and crunchiness during this study. It may be that the tomatoes used during the study with the 18-35 age group were not particularly distinguishable in firmness, compared to the samples used for the 45+ age group. However, this demonstrates that instrumental firmness measurements should be used in tandem with sensory analysis in any future work.

The participant group aged 45+ did not find significant differences between as many sensory categories for tomatoes from different temperature treatments as the participant 18-35 age group did, and only colour, ripeness, firmness and crunchiness were scored significantly different. This was most likely due to the negative association of aging on sensory perception as 63% of this participant group was aged 65+ (21% were aged 45-55 and 16% were aged 56-65 years of age), and reviews have concluded that taste detection thresholds for bitter, salty, sweet and sour increase with age, suggesting that taste perception generally declines during the natural ageing process (Methven *et al.*, 2012), and implying that the older the participant the more difficult it is to distinguish sensory properties. Additionally, Mojet et al., (2003) reported during research regarding taste perception and age that more time and more detailed instruction was required for their older participant group aged 60-75 years compared with their other participant group aged 19-33, which was also found during this study, as there was also a lot of confusion for the older individuals and it took a long time for them to complete the questionnaires in comparison to the younger participant group. Nevertheless, the four sensory categories that were found to be significantly different by this age group, especially colour, firmness and crunchiness, are some of the most important sensory descriptors of tomatoes. It is therefore important that in future sensory studies a mixed age range is used, and that the majority of participants are aged less than 65 year of age, but that volunteers over 65 years of age are not disregarded completely as they are still an important demographic of the average UK consumer, and it is likely that they purchase more fruit and vegetables than people of a younger age (HSCIC, 2012).

Since coloured lighting is generally used as a means to disguise the appearance of food during sensory analysis, encouraging the volunteers to use flavour and texture only (Meilgaard *et al.*, 2007), this is a novel approach to sensory analysis of tomatoes and was done in collaboration with Stuart Crichton, a fellow postgraduate student from Newcastle University who provided the concept of the blue light filters.

Conclusion

From this chapter it can be concluded that blue light filter did not have an effect on the sensory perception of tomatoes and did not affect the perception of tomato colour, although temperature treatment did have an effect and tomatoes from RT treatment were generally preferred by the consumer. Age had an effect on the sensory perception and participants from age group 18-35 were more able to distinguish differences between tomatoes from different treatments than those from the 45+ age group. Therefore, a mixed age group using unfiltered lighting will be used in the subsequent sensory analysis of tomatoes during this research project.

Chapter 5. Investigating the Effects of Room Temperature (23˚C) on Tomato Quality and Shelf life Compared with the Current Supply Chain Temperatures (average 12˚C)

5.1. Introduction

The results from Chapters 2-4 showed that shop bought round salad tomatoes that were stored at room temperature were generally scored higher in taste or consumer opinion than those that were kept in the refrigerator, and previous studies have also shown that warmer temperatures produce tastier tomatoes (Maul *et al.*, 2000). With the optimised sensory questionnaire and sample order developed during this research project, and using only normal light and a mixed participant age group, this can be further evaluated during this study.

Room temperature has also been found to have little detrimental effect on TSS, TA and pH levels in tomatoes when compared to colder temperatures of 5˚C, 10˚C or 12.5˚C (Maul *et al.*, 2000), and temperatures above 15°C have been found to be beneficial to total phenolic acid quantities (Pinheiro *et al.*, 2013) and lycopene levels (Toor and Savage, 2006). Tomato colour development also increases with increasing temperature, and this was demonstrated in tomatoes that were kept at 20˚C for 27 days which had higher red colouration than those kept at 12.5˚C, 8˚C, 6˚C and 2.5˚C (Biswas *et al.*, 2012).

Previous studies have indicated that higher postharvest temperatures may also enhance tomato shelf life (Chormova, 2010), but may cause higher weight loss through faster rates of respiration and therefore water loss (Shik and Kang, 2012). This rate, however, can be reduced with higher humidity (Paull, 1999). Warmer temperatures also generally reduce fruit firmness, and is mostly influenced by water loss, and this has been shown by Biswas et al., (2012) where tomatoes that were kept at 20˚C for 27 days had greatest firmness reduction than those kept at 12.5˚C, 8˚C, 6˚C and 2.5˚C. Furthermore, Vitamin C levels tend to increase in fruit when exposed to stressors, such as cold stress, suggesting that colder temperatures give higher levels of Vitamin C than warmer temperatures (Ioannidi *et al.*, 2009). This was shown by Campos et al., (2010) where tomatoes kept at 10˚C had higher levels of ascorbic acid compared with those kept at 24˚C for 72 hours.

Within commercial supply chains it is considered that temperatures of 10-14°C are optimal for the storage and transport of tomatoes (Chapter 1, Table 3), and generally during supply chain storage it has been assumed that deviations towards lower temperatures are more beneficial and less problematic than increasing temperature due to the belief that low temperatures are advantageous to shelf life. Temperatures of 13˚C or lower, however, induce CI in tomatoes (Hobson, 1987; Maul et al., 2000).

Few studies have had the opportunity to work closely with supermarkets to investigate the effects of supply chain temperatures on fruit quality, and since there is a large amount of evidence to suggest room temperature improves tomato quality in terms of taste, colour development, various nutritional components and even shelf life compared with lower storage temperatures, a study comparing supply chain temperatures with room temperature merits researching.

Aims and Hypotheses

The overall aim of this study was to evaluate the impact of examples of relevant temperature regimes through a commercial supply chain from harvest through to the point of purchase, and after sale with the consumer, on tomato quality and shelf life.

Hypotheses

- Room temperature storage of tomatoes after harvest positively affects the sensory outcome, colour development, and the carotenoid and phenolic compound accumulation, compared with supply chain or refrigeration temperatures.
- Cold storage of tomatoes after harvest reduces the total soluble solids and titratable acidity accumulation, but reduces the Vitamin C breakdown, and weight and firmness losses compared with room temperature.
- Temperature does not have an effect on tomato pH levels
- Room temperature storage after harvest relieves CI occurrence in tomatoes compared with supply chain temperatures during pre-sale storage or refrigerator temperatures during post-sale storage, seen by increasing shelf life.

5.2. Materials and methods

5.2.1. Tomatoes

Two 12-kg crates of freshly harvested round salad tomatoes (*Lycopersicon esculentum* Mill), variety Encore, at ripening stage three (there are six ripening stages, with stage one being green, and stage six being red) (López Camelo and Gomez, 2004) were collected from the grower (Jan Bezemers & Sons, Cleveland Nurseries, Stokesley, UK) and stored at RT. An additional two crates from the same batch and with the same harvest time were also labelled and sent through the standard supermarket supply chain (SC) until the crates reached the local supermarket in the morning of day 7 after harvest. The recorded temperatures during the supply chain ranged from 3.5°C to 25°C, with an average temperature of 12°C. On day 7, tomatoes from SC and RT treatments were subjected to quality analysis and sensory tested by 42 people. Half of the remaining tomatoes from each temperature treatment were then moved to RT and the other half to F treatment. This gave four new temperature treatments: tomatoes that had been through the SC and then moved to F (SCF), or to RT (SCRT), and tomatoes that had been kept at RT and then moved to F (RTF) or kept at RT (RTRT) (Figure 38). The tomatoes were kept in these new conditions for four days, still in the open crates, until they were subjected to further quality analysis and a second sensory testing session by 44 volunteers at day 11. Remaining tomatoes (approximately 100 fruits per treatment) were kept in these conditions and observed for full shelf life in terms of disease infection. Temperature and humidity were monitored using digital data loggers (EBI 20, Ebro, Xylem Analytical, Hertfordshire, UK), which took recordings every minute.

During the first day of the experiment the RT tomatoes experienced ≤24 hours at 26°C due to a problem with the temperature control of the chamber. Average humidity for SC/F and RT treatments were 70.5% and 47.3% respectively.

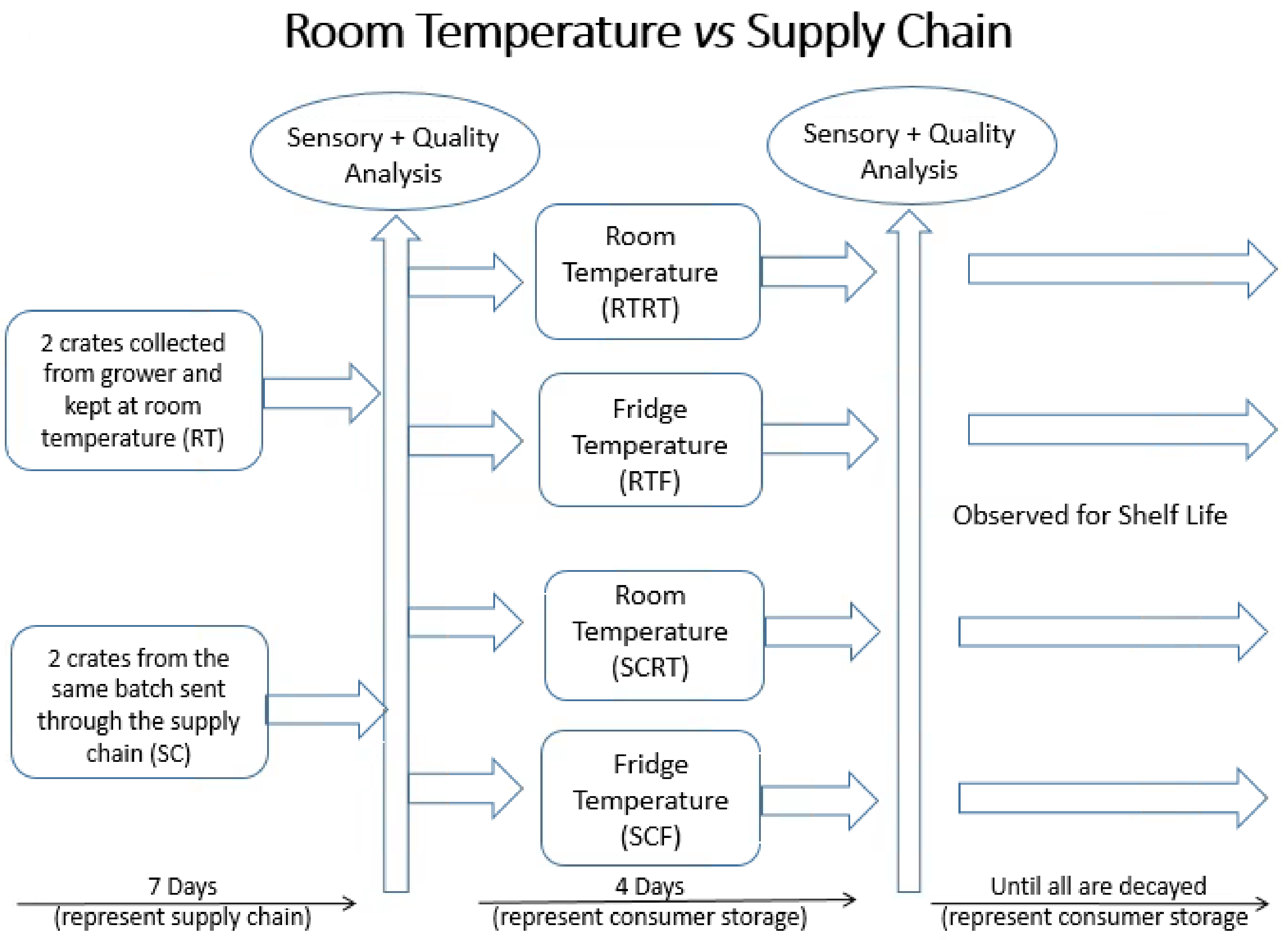

Figure 38 Flow Diagram for a Study Investigating Room Temperature Storage Compared with Supply Chain Temperatures. Flow diagram shows the experimental procedure of this study.

5.2.2. Sensory Analysis

Sensory analysis was as described in Chapter 3 using a mixed sample order. Participants were presented with two or four samples at a time (at day 7 and 11, respectively). Each panel member assessed either five (day 7) or four (day 11) sets of samples with the sample order switched to avoid bias.

5.2.3. Colour

Analysis of colour was done by fellow postgraduate student Stuart Crichton from the School of Electrical and Electronic Engineering, Newcastle University. Images of eight (day 7) or four (day 11) tomatoes from each treatment were taken using a spectro-radiometrically calibrated hyperspectral camera and mirror housing (Specim V10-E, Specim, Oulu, Finland), using a Schneider 23mm 1.4 compact C-Mount lens (Schneider Optics, CA, USA) in combination with a custom built LED illumination system (Mackiewicz *et al.*, 2012) (Gamma Scientific, CA, USA) (Figure 39) in conjunction with the Institute of Neuroscience at Newcastle University, UK.

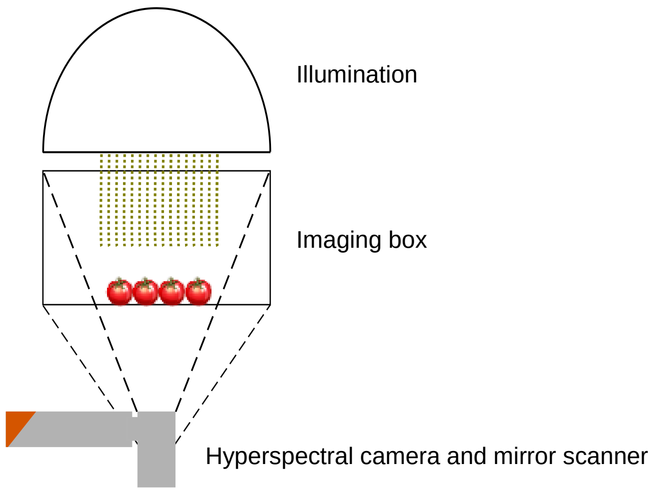

Figure 39 The Imaging System for the Colour Analysis of Tomatoes. Figure is courtesy of Stuart Crichton, Newcastle University

5.2.4. Weight loss (%)

Eight tomatoes from each of the two initial treatments that were assessed for colour on day 7 were then weighed (ae Adam equipment, Milton Keynes, UK) and individually labelled with stickers, the weights of which were deducted from the tomato weight (7±2mg). After four days in the new temperature treatments the now four labelled tomatoes from each treatment were re-tested for colour and weight and weight loss (%) calculated using the formula described in Chapter 2.

5.2.5. Tomato Firmness

Firmness method was as described in Chapter 2. Eight tomatoes from each treatment were analysed for deformation and penetration of the whole fruit. It was decided not to test for half fruit deformation due to time limits.

5.2.6. Carotenoid Analysis

Halves of four tomatoes from each treatment were sliced, placed in labelled bags and frozen at -80°C until later freeze dried. Freeze dried samples were powdered using a Cyclotec 1093 Sample Mill (Oy Cyclotec, Helsinki, Finland). Carotenoid analysis was adapted from the method of Chormova (2010). 1g of freeze dried tomato was homogenised with 3.75ml of ethyl acetate, covered and stored in the refrigerator overnight. Samples were then centrifuged at 4000rpm and 5°C for 20 minutes, and the supernatant removed. 0.75ml of ethyl acetate was then added to the remaining tomato in the tube and left in the refrigerator to extract for 1 hour. Samples were centrifuged again and supernatant removed and a further 0.5ml of ethyl acetate was added to the tubes and left in the refrigerator for another hour. The samples were centrifuged again and supernatant removed. The collective supernatant was then filtered through Whatman No.1 filter paper (Whatman, Kent, UK) and was then ready for HPLC analysis.

A Shimadzu Prominence system (Shimadzu Corporation, Kyoto, Japan) consisting of a quaternary pump, photodiode array detector, a column temperature control module and an autosampler set to take 20µl from each vial with a flow rate of 1ml/min was used. Carotenoid pigments were separated on a Phenomenex HyperClone column (250 x 4.6

mm, 5 micron) (Phenomenex, CA USA) kept at 30°C. Methanol and ethyl acetate (Fisher Scientific, Cambridge, UK) were used during the HPLC process and the mobile phase gradient used was as follows: 100% methanol at initiation, 65% methanol + 35% ethyl acetate at 13mins, 50% methanol + 50% ethyl acetate at 17mins, 100% ethyl acetate at 20mins and 100% methanol at 27mins until 32 mins. The total run time for each sample was 32 mins. Concentrations of carotenoids were calculated and expressed at mg/100g fresh weight (FW) using the response factors for all-trans lycopene, β-carotene and lutein determined from authentic standards of known concentration.

5.2.7. Phenolic Compound Analysis

Phenolic compounds were analysed based on a method by Bennett et al (2003). 40mg of freeze dried tomato sample was extracted with 950µl methanol (70%). A Techne Dri-Block DB-3D (Bibby Scientific, Staffordshire, UK) (70°C) was used to assist the extraction and samples were also vortex mixed (VX-2500 Multi-Tube Vortexer, VWR, Leicestershire, UK) every 5 minutes until 20 minutes. After centrifugation (accuSpin 3R, Fischer Scientific, Leicestershire, UK) at 4000rpm and 5°C for 20 minutes, 600µl of supernatant was then completely air dried using nitrogen gas (BOC, Guildford, UK) and a heat block at 50°C. Samples were then suspended to their original volume with deionised water (NANOpure Diamond, Barnstead, CA, USA) vortex mixed and then filtered into HPLC vials.

HPLC analysis was as above for carotenoids with the autosampler set to take 20µl injections from each vial and with a flow rate of 1ml/min. Separation of phenolic pigments required the HyperClone column (250 x 4.6 mm, 5 micron) (Phenomenex) to be kept at 25°C. Buffers A (0.1% trifluoroacetic acid (TFA) in H_2O) and B acetonitrile (ACN) (Fisher Scientific, Cambridge, UK) were used with a mobile phase gradient as follows: 100 % A + 0% B at initiation until 5 mins, 17% B at 15 mins until 17 mins, 25% B at 22 mins, 35% B at 30 mins, 50% B at 35 mins, 100% ACN B at 40 mins until 50 mins, 100% A at 55 mins until 65 mins. The total run time for each sample was 65 mins. Chlorogenic acid (quantified at 280nm) and rutin (quantified at 320nm) (Sigma-Aldrich, Dorset, UK) were used as reference standards for sum of caffeic acids and sum of flavonoids respectively. Calibration curves of 1-50µg/ml for each of these were created and the line equation was used to calculate concentrations in µg/g FW. Since there was a large number of peaks that could not be identified as caffeic acid derivatives or flavonoids the concentration of the unidentifed peaks were calculated from their areas using a combined average created from the line equations of the standard curves of the reference standards chlorogenic acid and rutin mentioned above.

5.2.8. Chemical Constitutes: pH, Acidity, Total Soluble Solids and Vitamin C

The measurement of pH, TA and TSS was as described in Chapter 2. Vitamin C was analysed based on the AOAC (2000) method by mixing 5ml of the supernatant with 2ml 0.4% oxalic acid (Thermo Fisher Scientific, Geel, Belgium) solution and diluting to 50ml. The samples were titrated against 2.5ml 2.6-dichlorophenolindophenol (DCPIP) dye (Sigma-Aldrich, Dorset, UK), and results were expressed as Vitamin C mg/100g FW.

5.2.9. Tomato Shelf Life

Tomatoes (initially approximately 100 per treatment) were observed three times a week until they were all decayed. At each observation the number of tomatoes with any visible microbial growth was recorded and the affected tomatoes were removed to avoid contamination. Wrinkly tomatoes were not removed as this study evaluated tomato pathogen infection. A percentage survival score was calculated using the following formula:

$$\text{Surviving tomatoes (\%)} = \frac{\text{Number of healthy tomatoes in replicate}}{\text{Total number of tomatoes in replicate at initiation}} \times 100$$

5.3. Statistical Analysis

A p-value of less than 0.05 was considered significant. Multivariate analysis of variance (MANOVA) and with one way analysis of variance (ANOVA) was used for sensory data at day 7, and ANOVA was used for all the other day 7 data. General Linear Model (GLM) was used for all day 11 data. Carotenoid and phenolic data were logarithmically transformed for statistical analysis, and then back-transformed to return the data into range. Survival calculation was performed using the Kaplan-Meier Estimator (Kaplan and Meier, 1958) for analysis of shelf life data. Normality of data was checked using probability of residuals and residuals versus fits plots. If data were not normal they were logarithmically transformed.

5.4. Results

5.4.1. Sensory Testing

At day 7 the MANOVA results showed significant differences between the consumer scores for tomatoes from SC and RT pre-sale treatments ($F=88.275$, $DF=9, 324$, $p<0.001$, Wilks' $\lambda= 0.289$) (Figure 40). Most noticeably, scores in colour and ripeness were both much higher for RT tomatoes (by 89% and 70% respectively). SC tomatoes were 36% firmer and 39% crunchier, however the overall opinion score for RT tomatoes was 25% higher than for tomatoes from SC treatment, and SC tomatoes for aroma and flavour were 18% and 21% lower than those for RT tomatoes.

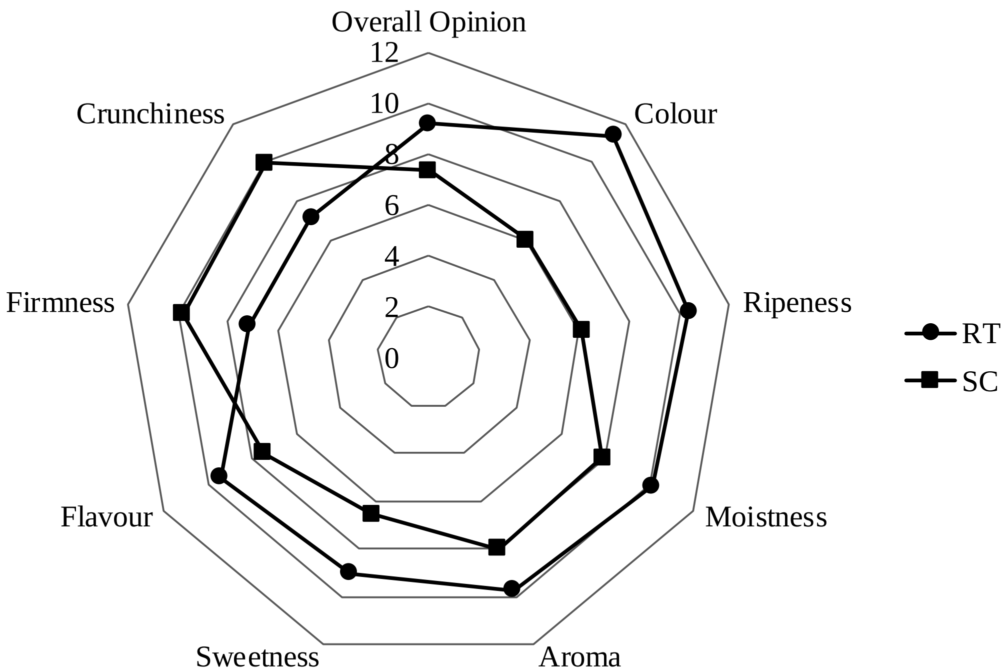

Figure 40 Spider Plot of Mean Sensory Scores for Tomatoes. Fruits were stored for 7 days at either RT (23˚C) or SC (average 12˚C) treatments. Standard error of the mean (SEM) for each sensory category ranged from 0.15 to 0.25 with an average of 0.20

At day 11 treatments RTF and SCRT produced tomatoes that were very similar from a sensory perspective, and there was ≤4% variation in the scores for all the 9 sensory categories that the tomatoes were assessed for by the participants (Figure 41), and this can be seen by the overlap in sensory results on the spider plot. Participants rated RTRT tomatoes highest for ripeness, scoring almost twice as highly as SCF and 17% and 16% higher than the scores of tomatoes from RTF and SCRT respectively. Higher temperature exposure also produced more aromatic tomatoes; RTRT tomatoes had 46% more aroma than SCF tomatoes, and were 10% more aromatic than SCRT and RTF tomatoes.

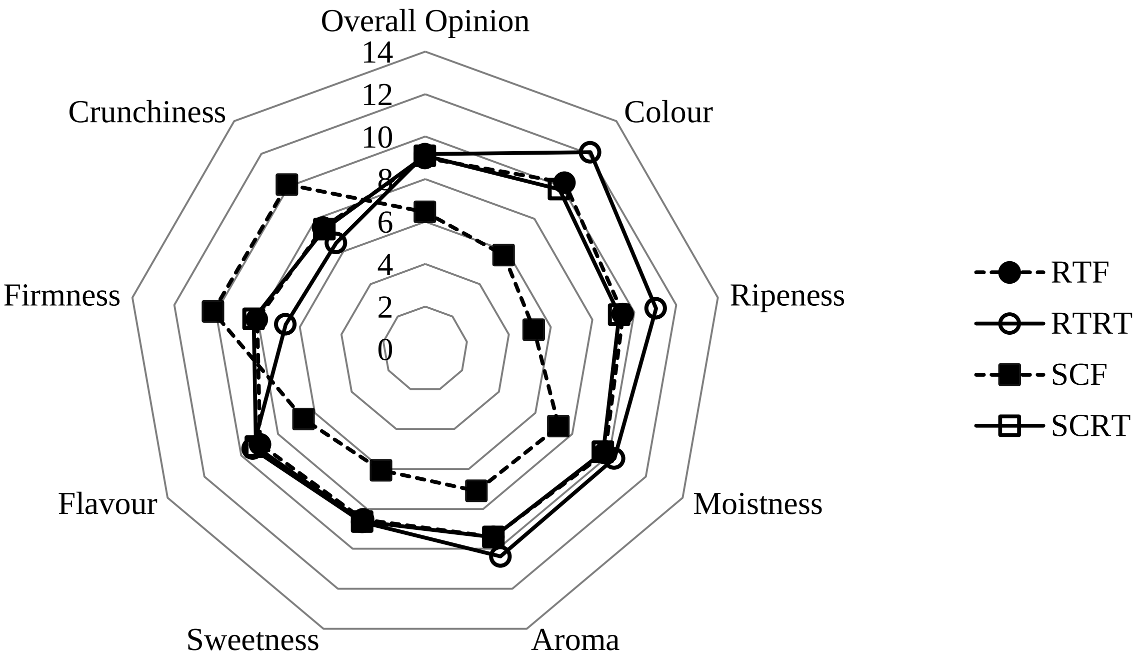

Figure 41 Spider Plot of the Mean Sensory Scores of Tomatoes. Fruits were stored at either RT (23˚C) or SC (average 12˚C) for 7 days, and for a further four days at RTF, RTRT, SCF or SCRT (day 11). Standard error of the mean (SEM) for each sensory category ranged from 0.15 to 0.35 with an average of 0.24.

With the exception of firmness and crunchiness, SCF tomatoes had the lowest scores in all sensory categories compared with the other treatments (Figure 41). This was most prominent for the scores given to the tomatoes for flavour, sweetness and moisture where the other treatments were given between 35-42% greater scores than tomatoes from SCF. SCF tomatoes were significantly firmer and crunchier than tomatoes from the other treatments, most noticeably 52% firmer and 55% crunchier than those from RTRT treatment. This is a similar outcome to the first session where the coldest treatment also produced the crunchiest and firmest fruit. Since SCF tomatoes were frequently scored the lowest in most sensory categories when compared with the other treatments, this was mirrored in the overall opinion scores for SCF tomatoes which was 30% lower than the tomatoes from the other treatments, making SCF tomatoes the consumers' least favoured tomatoes, irrespective of them being firmer and crunchier. This observation is very important as storing supermarket tomatoes in the refrigerator (SCF) is very common by the UK consumer.

The GLM analysis showed pre-sale and post-sale storage phases were both found to have highly significant effects on all sensory categories (all $p<0.001$) and an interaction between pre-sale and post-sale storage was found for sensory categories (all $p<0.001$), except firmness ($p=0.438$).

To summarise, in terms of consumer perception, SC treatment produced tomatoes that were of lower quality compared with RT treatment at day 7. Addtionally, by day 11, the coldest storage treatment F continued to have a negative effect on tomato quality and tomatoes from SCF treatment were scored as the consumers least favourite compared to all the other treatments. Therefore, the coldest treatment always had the most detrimental effect on tomato sensorial quality.

5.4.2. Colour

At day 7 the hyperspectral camera data showed SC tomatoes had 23% higher L and 31% higher b* values, but 5% lower a* values than tomatoes from RT, and treatment was found to have a significant effect on the L, a* and b* values of tomatoes ($p=0.035$, $p<0.001$ and $p<0.001$ respectively) (Table 14)

Table 14 Mean L, a* and b* Values of Tomatoes. Fruit were stored at either for 7 days at RT (23˚C) or SC (average 12˚C), and for a further four days at RTF, RTRT, SCF or SCRT (day 11). Numbers in brackets represent standard error.

Day	Treatment	L	a*	b*
7	**RT**	40.90 (0.64)	48.87 (0.75)	30.95 (0.58)
	SC	50.26 (0.84)	46.43 (0.73)	40.49 (1.13)
11	**RTF**	39.72 (0.71)	47.72 (1.51)	29.51 (0.94)
	RTRT	36.79 (0.88)	47.67 (1.02)	29.02 (1.14)
	SCF	47.15 (2.04)	44.46 (2.46)	38.62 (1.80)
	SCRT	37.13 (0.64)	46.27 (0.81)	27.16 (0.35)

By day 11 RTF and RTRT tomatoes had similar a* values and these were, most noticeably higher when compared with SCF tomatoes (Table 14). The highest L and b* values were found for SCF tomatoes which was expected since the lighter red colour will cause greater reflectance and the greatest green colouring. Only pre-sale treatment was found to have significant effects of L, a* and b* levels at day 11 ($p<0.001$, $p=0.001$ and $p<0.001$ respectively). Visual colour differences were also seen between tomatoes from different treatments (Figure 74, Appendix B).

To summarise, tomato quality, in terms of characteristic colour development, was lower at SC treatment compared with RT treatment and tomatoes from RT had higher a* values, and lower L and b* values. By day 11, the coldest treatment SCF also had the lowest colour development and had considerably higher L and b* values compared with tomatoes from all the other treatments, suggesting that colder temperatures reduce tomato quality in terms of colour development.

5.4.3. Carotenoids

At day 7 RT tomatoes had more than 3-fold more all-trans lycopene than SC tomatoes ($p=0.012$) (Table 15). However, no difference in the β-carotene and lutein levels was seen between treatments ($p=0.135$ and $p=0.065$ respectively). During the second part of the study tomatoes from the RTF and SCRT treatments had similar all-trans lycopene concentrations, whereas SCF tomatoes had a considerably lower content than the other treatments, noticeably by almost 5-fold than that of tomatoes from RTRT (Table 15).

The GLM data showed that all-trans lycopene content at day 11 was significantly affected by pre-sale treatments RT and SC ($p=0.002$), although post-sale storage at either F or RT for 4 days was not found to have a significant effect on the all-trans lycopene content at this time ($p=0.939$). Data from the GLM analysis also revealed an interaction amongst pre-sale and post-sale treatments, showing that pre-sale treatment followed by storage at RT during post-sale treatments (RTRT or SCRT) increased levels of all-trans lycopene, whereas F temperatures reduced the levels between day 7 and 11 ($p=0.018$). Similar to the first part of the study, no significant differences were seen between the β-carotene and lutein levels of tomatoes from different treatments, and this was seen for all factors investigated (Table 15).

In summary, RT treatment improved tomato properties in terms of lycopene, and levels were much higher in tomatoes from this treatment compared with those from SC treatment at day 7. By day 11, the coldest treatment SCF had the lowest all-trans lycopene contents, while tomatoes from the warmest treatment RTRT had the highest, suggesting that colder temperatures reduce tomato quality in terms of lycopene accumulation.

Table 15 Mean Carotenoid and Phenolic Compounds of Tomatoes. Fruits were stored for 7 days at either RT (23˚C) or SC (average 12˚C), and for a further four days at RTF, RTRT, SCF or SCRT. Numbers in brackets show standard error. Day 7 data was analysed by ANOVA and day 11 data was analysed by GLM.

Temperature Treatment	Lutein mg/ 100g FW	All-Trans Lycopene mg/100g FW	β-Carotene mg/100g FW	Sum of Caffeic Acid Derivatives µg/g FW	Sum of Flavonoids µg/g FW	Sum of Unidentified Compounds µg/g FW	Sum of Phenolic Compounds µg/g FW
RT	0.31 (0.01)	15.13 (2.09)	2.09 (0.07)	550.98 (117.02)	323.27 (72.04)	5119.16 (268.59)	5993.22 (220.07)
SC	0.10 (0.04)	4.46 (1.35)	1.28 (0.34)	817.29 (114.01)	286.26 (56.54)	4208.05 (225.70)	5321.14 (236.14)
p-value	0.065	0.012	0.135	0.021	0.874	0.002	0.060
RTF	0.31 (0.13)	8.24 (0.43)	1.23 (0.79)	388.04 (43.88)	267.88 (13.9)	3223.15 (482.10)	3913.83 (729.14)
RTRT	0.35 (0.07)	15.71 (2.17)	1.84 (0.88)	471.93 (32.23)	325.95 (25.15)	4525.14 (131.20)	5324.39 (188.99)
SCF	0.20 (0.07)	3.35 (1.82)	0.92 (0.38)	584.64 (45.85)	157.46 (49.80)	3119.20 (634.02)	3904.76 (712.16)
SCRT	0.22 (0.02)	6.17 (0.93)	1.69 (0.18)	475.55 (4.17)	289.30 (28.02)	4254.67 (158.48)	5022.79 (176.46)
Source of Variation				**Probability**			
Pre-sale Treatment	0.088	0.002	0.463	0.021	0.193	0.814	0.862
Post-sale Treatment	0.976	0.939	0.683	0.946	0.115	0.126	0.128
Pre-sale x Post- sale Treatment	0.651	0.018	0.070	0.025	0.399	0.940	0.772

5.4.4. Phenolic Compounds

At day 7 the levels of sum of caffeic acid derivatives were close to 50% higher in tomatoes from SC treatments than those from RT treatment (p=0.021) (Table 15), whereas the results observed for flavonoids showed no significance difference between treatments (p=0.874). Keeping freshly harvested tomatoes at RT or SC for 7 days did have a positive effect on the sum of unidentified compounds, which were considerably greater in tomatoes from RT treatment by 22% (p=0.002) (Table 15), and levels of sum of phenolic compounds were overall 13% higher in tomatoes from RT than those from SC treatment, however this was not found to be statistically significant (p=0.060) (Table 15).

Neither pre-sale (p=0.193) nor post-sale (p=0.115) treatments had a significant effect on flavonoid levels by day 11, and so no statistical interaction between pre-sale and post-sale treatments was seen (p=0.399) (Table 15). Pre-sale storage did have significant effects on the caffeic acid derivative levels found in tomatoes from different treatments at day 11 (p=0.021). SCF tomatoes had the highest levels of sum of caffeic acid derivatives, most noticeably 39% more than tomatoes from RTF treatment, but did not vary largely from tomatoes from any of the other treatments. Caffeic acid levels decreased between sessions for all treatments, and a statistically significant interaction between pre-sale and post-sale storage was seen from the GLM output (p=0.025).

Interestingly, tomatoes that had been exposed to SC pre-sale treatment and then kept at RT during post-sale storage (SCRT) had a much larger decrease in caffeic acid levels compared to those from RT pre-sale treatment that were also kept at RT during post-sale treatment (RTRT) (72% *versus* 17% decrease respectively), whereas tomatoes that were kept at F during post-sale storage (SCF and RTF) had similar levels of decrease in caffeic acid derivatives (28% and 30% respectively).

RTRT tomatoes had the highest sum of unidentified phenolic compounds and sum of total phenolic compounds by day 11 compared with the other treatments, however, no effects of the independent storage phases or an interaction was found from the GLM data (Table 15).

In summary, tomato properties in terms of unknown phenolic compounds' accumulation was higher in tomatoes from treatment RT at day 7, while caffeic acid derivatives' contents were higher in tomatoes from SC treatment. At day 11, the coldest treatment was also the highest in caffeic acid derivatives and this was seen in tomatoes from SCF compared with tomatoes from the other treatments. However, quality in terms of flavonoids and sum of phenolic compounds wasunaffected by temperature treatment at both phases of the study.

5.4.5. Firmness: Deformation and Penetration of Whole Fruit

None of the temperature treatments caused significant differences in the deformation of the whole fruit at day 7 (p=0.254), while tomatoes from SC required more force to penetrate than those from RT treatment at this time (p<0.001) (Figure 42).

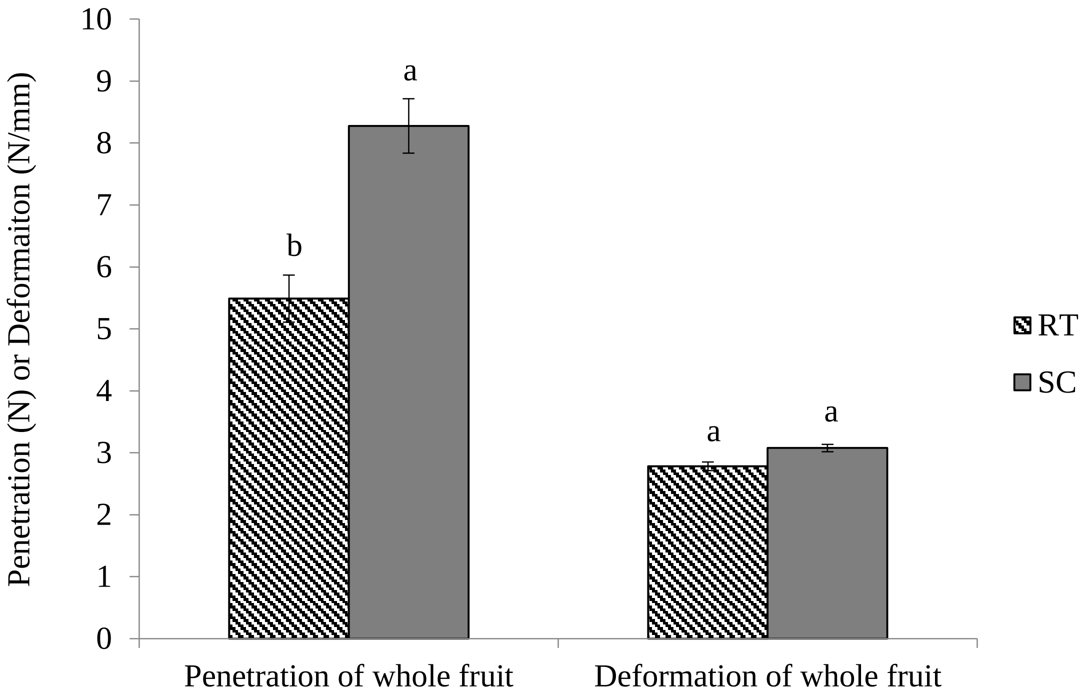

Figure 42 Mean Tomato Firmness at Day 7. Firmness was measured as penetration (N) and deformation (N/mm) of tomatoes. Tomatoes were stored for 7 days at either RT (23˚C) or SC (average 12˚C). Error bars represent standard error. Bars with the same letter in each column are not significantly different (ANOVA)

At day 11 tomatoes from SCF treatment required the greatest force to penetrate, while tomatoes from RTRT were the least firm (Figure 43). Only the pre-sale treatments RT and SC had a significant effect on the force to penetrate the whole fruit at day 11 ($p<0.001$). Similar to the results at day 7, the deformation values of the whole tomato were similar for those from all treatments at day 11 and none of the factors investigated were found to have a significant effect ($p=0.383$ for pre-sale treatment, $p=0.470$ for post-sale treatment and $p=0.543$ for the interaction between pre and post-sale treatments).

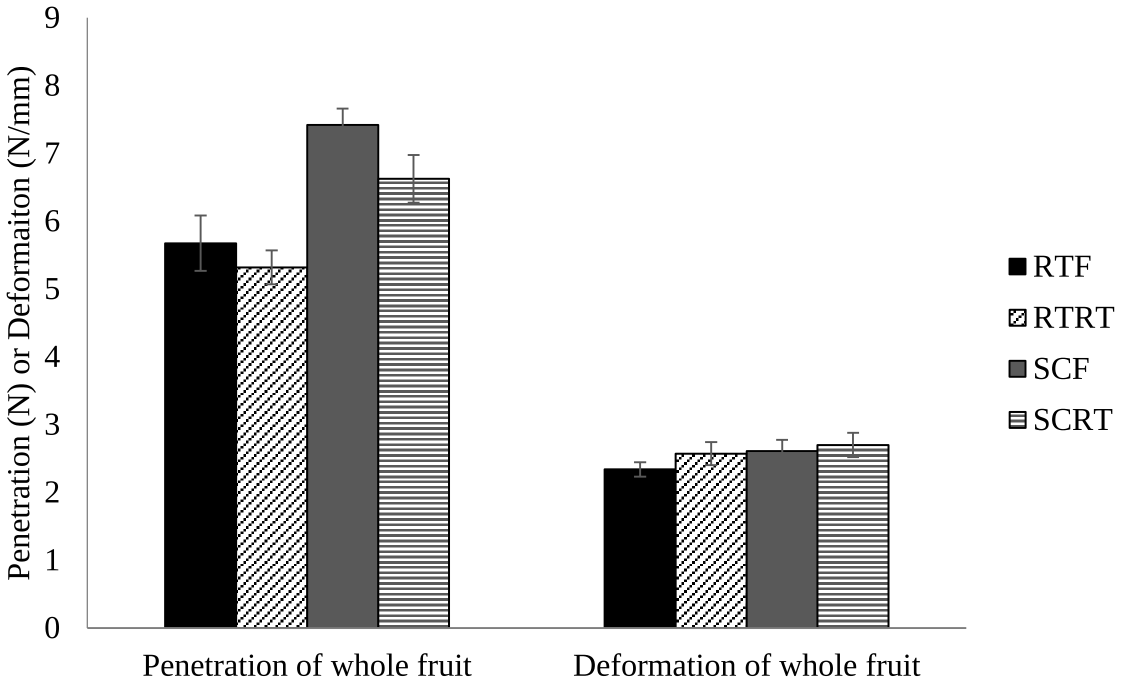

Figure 43 Mean Whole Fruit Firmness at Day 11. Firmness was measured as penetration (N), and deformation (N/mm) of tomatoes after being stored for 7 days at RT (23˚C) or SC (average 12˚C); and for a further four days at RTF, RTRT, SCF or SCRT. Error bars represent standard error.

In summary, tomato quality in terms of penetration was always highest at tomatoes from the coldest treatments at both time points (SC at day 7 and SCF at day 11). Firmness quality in terms of deformation however, was unaffected by any of the treatments.

5.4.6. Weight loss (%)

Only post-sale treatment was found to have a statistically significant effect on weight loss, with tomatoes that had subsequent storage at RT treatment (RTRT and SCRT) having the largest weight loss, while those from RTF and SCF were considerably lower (p=0.008) (Table 16), and this was most likely caused by greater respiration rates and therefore water loss seen at warmer temperatures and also due to the lower relative humidity seen at RT treatment compared with F treatment.

Tomato quality in terms weight loss was preserved during storage at F treatment, and levels were much lower than after storage at RT treatment by day 11.

5.4.7. Chemical Constitutes: pH, Titratable Acidity, Total Soluble Solids and Vitamin C

The pH, citric acid and Vitamin C content of tomatoes from either pre-sale treatments RT or SC were not significantly different at day 7 (p=0.441, p=0.702 and p=0.168 respectively) (Table 16). Higher temperature of RT did, however, result in significantly higher TSS content during the first phase of the research (p=0.021). This was supported by the sensory analysis in which RT tomatoes were also rated the sweetest by the consumer (Figure 40).

By day 11 tomatoes from SCRT treatment had 53% and 74% more Vitamin C than those from RTRT and RTF, but similar levels to that of SCF tomatoes. Little change between day 7 and 11 was observed for levels of acidity and TSS, whereas, pH was seen to increase between day 7 and 11. Only Vitamin C values at day 11 were found to be significantly affected by pre-sale treatment at SC or RT (p=0.003), whereas pre-sale storage had no significant effect on pH, titratable acidity and TSS levels recorded at day 11 (p=0.097, p=0.599 and p=0.796 respectively) (Table 16).

In summary, fruit quality in terms of pH and TA was unaffected by temperature treatment at both day 7 and day 11. RT treatment had a positive effect on TSS contents at day 7, but by day 11 temperature treatment was not seen to have a significant effect on TSS contents. At day 7 treatment was not found to have an effect on Vitamin C, however, by day 11 tomatoes from SCRT treatment had the largest Vitamin C contents compared with tomatoes from the other treatments.

Table 16 Mean Chemical Constitutes and Weight Loss (%) of Tomatoes. Fruit was stored for 7 days at RT (23˚C) or SC (average 12˚C), and for a further four days at RTF, RTRT, SCF or SCRT. Numbers in brackets represent standard error. Day 7 was analysed by ANOVA and day 11 data was analysed by GLM.

Temperature Treatment	pH	Weight Loss (%)	Total Soluble Solids (°Brix)	Citric Acid g/100g FW	Vitamin C mg/100g FW
RT	4.09 (0.10)		4.60 (0.01)	0.211 (0.01)	21.96 (0.47)
SC	3.99 (0.03)		4.25 (0.01)	0.186 (0.06)	24.2 (1.57)
p-value	0.441		0.021	0.702	0.168
RTF	4.21 (0.04)	0.39 (0.14)	3.90 (0.74)	0.224 (0.09)	13.84 (0.67)
RTRT	4.18 (0.04)	1.78 (0.70)	4.45 (0.11)	0.253 (0.01)	15.70 (1.82)
SCF	4.10 (0.03)	0.34 (0.14)	4.70 (0.56)	0.308 (0.09)	20.86 (2.36)
SCRT	4.14 (0.03)	2.21 (0.20)	5.10 (0.85)	0.141 (0.02)	24.39 (1.88)
Source of Variation			**Probability**		
Pre-sale Treatment	0.097		0.796	0.599	0.003
Post-sale Treatment	0.917	0.008	0.931	0.369	0.383
Pre-sale x Post- sale Treatment	0.717		0.863	0.209	0.785

5.4.8. Tomato Shelf Life

Keeping RT tomatoes at room temperature (RTRT) increased tomato shelf life (resistance to pathogen infection) by 63% when compared with subsequent refrigerator storage (RTF) ($p<0.001$) (Figure 44). The median shelf life was 24 days for SCF; 27 days for RTF; 45 days for RTRT and 64 days for SCRT. SC tomatoes that were kept at room temperature also survived for almost one and a half times longer than SCF tomatoes ($p<0.001$). Tomatoes from SCRT also had longer survival rate than those from RTF treatment ($p<0.001$), while no statistically significant difference was found between the survival times of tomatoes from RTRT and SCRT ($p=0.200$). None of the treatments showed any visible signs of CI during this study, except the increased susceptibility to rot and mould which reduced shelf life when kept at F.

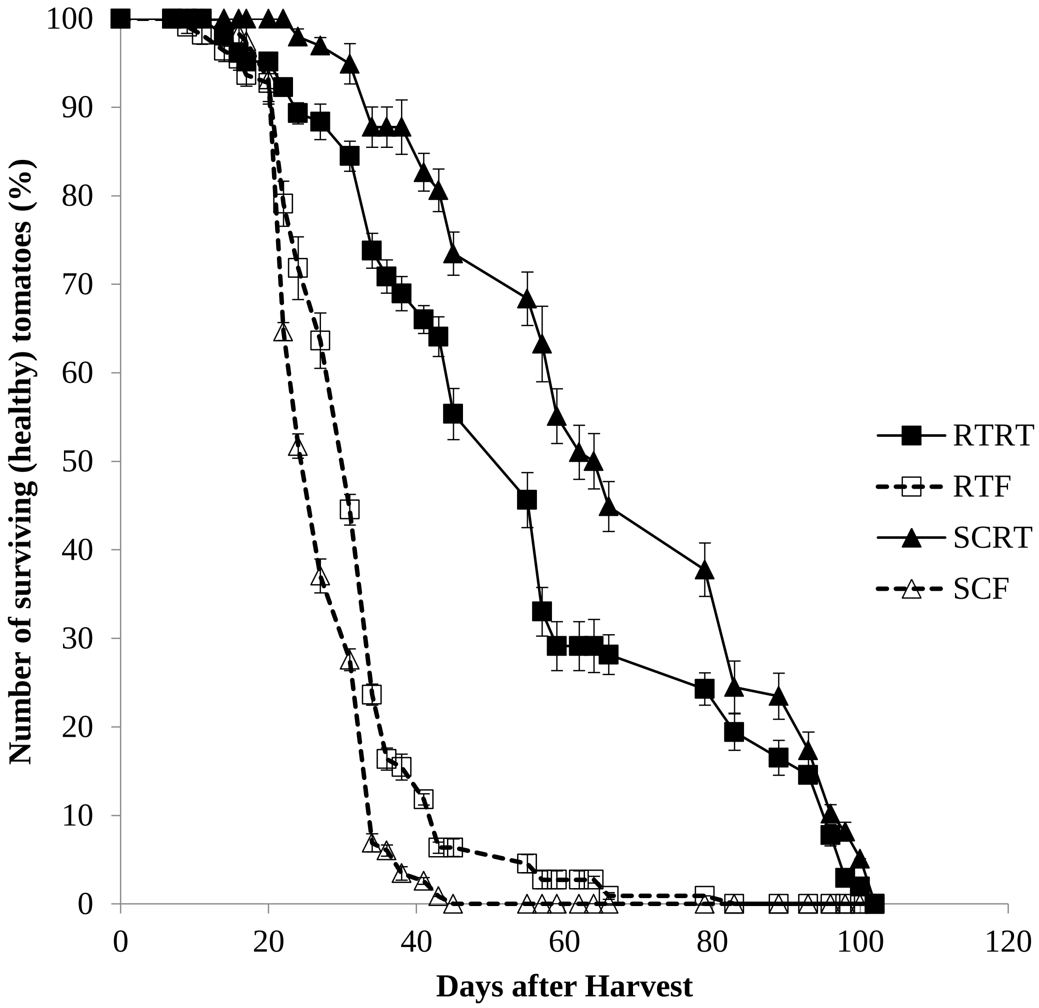

Figure 44 Mean Survival Scores (%) of Tomatoes. Fruit were stored for 7 days at RT (23°) or SC (average 12°C); and at RTF, RTRT, SCF or SCRT for the remainder of the study. Bars represent standard error.

In summary, post-sale RT storage has a positive effect on the shelf life in terms of disease resistance of tomatoes, and this was most substantial in tomatoes that had prior storage at SC treatment, while the coldest treatment SCF had a negative effect on tomato disease resistance.

5.5. Discussion

Cold storage at SC treatment seemed to inhibit all changes in sensory characteristics associated with ripening uniformly, so at day 7 there was very clear statistical significance difference between tomatoes from SC and RT treatment. CI has been reported to reduce ripe flavour and aroma, and increase off-flavours (Hobson, 1987; Maul *et al.*, 2000), so this may explain the lower sensory scores, since temperatures during SC storage were below 13˚C, which is CI inducing (Kader *et al.*, 1978; Farneti *et al.*, 2010; Biswas *et al.*, 2012)

Little variation was seen in the overall opinion scores for tomatoes from all the treatments in phase two, except for tomatoes from SCF which were much lower, suggesting that refrigerator storage can exacerbate the deterioration of sensory perception already apparent from 7 days SC storage. RTF and SCRT tomatoes were equal in sensory outcome, and also in lycopene accumulation, therefore suggesting that the order of applying chilling or room temperatures does not have an effect on the sensory outcome, whereas the duration of exposure to chilling temperatures does.

It was surprising to find such a large difference in the consumer preference scores between RTF tomatoes and SCF tomatoes even though they both experienced post-sale storage at refrigerator temperatures for four days, suggesting that F temperatures are less detrimental in tomatoes if they are applied after fruit has reached an appropriate maturity. Previous research has shown that keeping tomatoes at warmer temperatures of 38°C for 48 hours before non-freezing chilling temperatures of 2°C for 3 weeks reduces the severity of CI as compared to those that were not exposed to the warmer temperatures before cold storage (Lurie *et al.*, 1997), so this may explain why RTF were favoured.

RT treatment increased tomato colour development compared to tomatoes from SC treatment during phase one in this study. Moreover, after comparing the difference in SCF and SCRT tomato colour values at day 11 with the values seen for SC tomatoes at day 7, it is clear that the rate of colour change is delayed in the coldest treatment SCF. It can therefore be concluded that lower temperature treatments delay the ripening process, and therefore quality.

RT treatment had a positive effect on the accumulation of all-trans lycopene, and levels were lower in tomatoes that had been exposed to SC treatment compared to those from RT treatment, suggesting that SC temperatures reduce carotenoid accumulation in terms of lycopene. However, treatment did not affect β-carotene or lutein concentrations significantly.

SCF tomatoes had lower contents of all-trans lycopene than tomatoes from the other treatments most noticeably when compared with that of tomatoes from RTRT treatment, presumably since the warmer treatments have allowed the tomatoes to be more ripe, and lycopene content increases with fruit ripening (Khan *et al.*, 2008). Post-sale treatment alone was not found to have a significant effect on all-trans lycopene accumulation, however, an interaction was seen between pre-sale and post-sale storage, and post-sale storage at F did appear to cause a decline in all-trans lycopene levels while post-sale RT treatment allowed levels to increase. This highlights the importance of keeping freshly harvested tomatoes above chilling temperatures during the first 7 days of storage, and that this is more impacting than the consumer phase storage. Refrigeration storage did not have a statistically significant effect on β-carotene and lutein contents, although β-carotene levels were lower at day 11 in RTF and SCF tomatoes than those recorded at day 7 for RT and SC tomatoes. It can therefore be concluded that although not significant, F post-sale treatment has a negative effect on carotenoid accumulation in terms of lycopene and β-carotene compared with post-sale RT treatment.

The sum of caffeic acid derivatives was almost twice as high in tomatoes from SC treatments than in those from RT. Since plants often respond to stressors, such as being eaten by predators and chilling injury, by synthesising polyphenols (Lattanzio *et al.*, 2009), this may explain this occurrence. However, the largest sum of unknown phenolic compounds was seen in tomatoes from RT treatment. This may have occurred as SC temperatures dropped to as low as 3.5°C and this could have caused the vacuoles which hold the enzymes phenylalanine ammonialyase and hydroxycinnamoyl quinate tranferase which are responsible for polyphenol synthesis to rupture as suggested by Toor and Savage (2006). Flavonoid content has been reported to be relatively stable in fruit during postharvest storage. This was seen in papaya rutin levels where no differences were seen amongst fruits that had been stored at 1°C or 25°C for 12 days (Rivera-Pastrana et al., 2010). In another study, total flavonoid levels were found to be unchanged during 14 days storage at room temperature in banana, apricot and plum fruits, and this was also the case for plums that were kept at 4°C for the same amount of time (Kevers et al., 2007), so this may explain the lack of difference observed between temperature treatments throughout this research. It can be concluded therefore that SC temperatures did not reduce phenolic compound accumulation in terms of caffeic acid derivatives, although did reduce the levels of unknown phenolic compounds, while having no effect on flavonoid contents or the sum of phenolic compounds.

At day 11 levels of flavonoids, unidentified phenolic compounds or sum of phenolic compounds were highest in tomatoes from RTRT treatment, suggesting that refrigeration storage does reduce phenolic accumulation, although this was not by enough for this to be statistically significant. Tomatoes from SCF had the highest levels of caffeic acid derivatives, although this was not found to be significantly affected by post-sale refrigeration storage. Therefore, it can be concluded that refrigeration temperatures generally do not reduce tomato phenolic compound levels enough for it to be a significant effect.

Storage at RT treatment increased weight loss and also reduced tomato firmness (fruit penetration) compared to SC treatment, along with receiving lower scores for the sensory categories 'firmness and crunchiness'. Reduced crunchiness and increased weight loss are associated with the degradation of fruit cell walls (Fischer and Bennett, 1991; Hadfield and Bennett, 1998) and increased water loss through transpiration, suggesting that RT temperatures encourage ripening in the tomatoes. Since low fruit firmness and high weight loss is generally associated with reduced quality, it can be concluded that RT reduces tomato quality in this respect

Storage at SC treatment for 7 days also reduced TSS accumulation compared to keeping tomatoes at RT treatment, however out of the chemical constituents this was the only one to be significantly affected and SC treatment did not have any effect on tomato TA, pH or Vitamin C levels at day 7. By day 11 no significant differences between treatments were seen for pH, TSS and citric acid content, suggesting that refrigeration temperatures do not have a negative effect on these chemical constitutes. Goren et al., (2010) also found only small changes in the TSS content and the acidity between tomatoes kept at 12°C, 20°C or 30°C for nine days, while Maul et al., (2000) found no differences in TA levels between tomatoes kept at 5°C, 10°C, 12.5°C or 20°C for up to twelve days, suggesting that differences in chemical constitutes can be seen between tomato types.

By day 11 tomatoes from SCRT treatment were significantly higher in Vitamin C contents compared with tomatoes from the other treatments. These results do not agree with the results of Goren et al., (2010) where Vitamin C concentrations were significantly higher in tomatoes kept at 20°C compared with those held at 12°C and 30°C for up to nine days. SCRT and SCF tomatoes were exposed to temperatures at or below 12°C for seven days, and during this time temperatures dropped as low as 3.5°C and since temperatures of 4°C had been found to reduce the rate of Vitamin C break down in tomatoes compared to storage at 25°C over a two week period (Sablani *et al.*, 2006), this may explain the lack of agreement. Post-sale refrigeration storage did not retain Vitamin C levels, and levels declined by 14% in tomatoes from SCF and 37% in tomatoes from RTF.

Post-sale storage greatly influenced the pathogen resistance of the product, as tomatoes that were not kept at refrigeration temperatures survived much longer than those that were. This was most apparent when comparing the survival time of tomatoes from SCF with those from SCRT. Therefore, it can be concluded that room temperatures increase tomato shelf life. It was interesting to find that tomatoes from the refrigerator treatments SCF and RTF had the lowest resistance to pathogen infection, especially SCF due to the common belief by supermarkets and consumers that the coolest treatments give the longest shelf life. The key difference between the data presented here and other published data is the long duration of the study, measuring tomato survival for up to 100 days. One factor that may have influenced the earlier pathogen infection of the refrigerator tomatoes in this research could be since the refrigerator store had an average relative humidity of 70.5%, whereas room temperature conditions had an average of 47.3%, and high relative humidity has been associated with the development of moulds (Shirazi and Cameron, 1992). It can be speculated, therefore, that post-sale refrigeration storage may be more beneficial to consumers if there was a lower relative humidity within a domesticated refrigerator. To challenge this concept five data loggers were placed in five domestic refrigerators in the Agriculture Building of Newcastle University and relative humidity was found to range from 36.1-58.0%.

Therefore this speculation may be reasonable since relative humidity in the domestic refrigerators was lower than the relative humidity of the chiller used in this study.

Although this research has provided information on the reduction of disease resistance seen in tomatoes kept at refrigeration temperature, a weakness is that there is no information on what types of disease the tomatoes suffered from. Therefore, in the subsequent research study types of decay, rot or mould are observed and also surface defects such as wrinkling/shriveling that occur during storage.

No visual signs of CI, such as surface pitting and uneven ripening were seen during the study. However, reduced consumer preference scores for tomatoes that were kept the coldest (SC in phase one, and SCF in phase two), are most likely to have occurred as a symptom of CI. Additionally, the earlier fruit senescence seen from the tomatoes that received post-sale F storage can be attributed to CI, giving higher susceptibility to moulds and rots (Hobson, 1987; Maul *et al.*, 2000).

Conclusion

The results from this study are in agreement with previous literature regarding sensory effects (Maul *et al.*, 2000), colour and carotenoid content (Arias *et al.*, 2000; Opara *et al.*, 2012), confirming that the temperatures used in the supply chain were so low that the normal ripening was inhibited. The novel and key findings from this study are the improvement of taste and shelf life found for tomatoes from the warmer treatments. The results of this study indicate the potential benefits of higher temperatures than those normally used in the supply chain for this fruit species. It showed that the presumed benefits of refrigeration either did not exist (shelf life was significantly shorter if subsequently stored at F), not relevant (insignificant improvement in shelf life if subsequently stored at RT, higher vitamin C content would be offset by any reduction in consumption) or not appreciated by most consumers (significantly more firm and crisp fruit).

Although these data show RT to produce preferable tomatoes to SC, it is likely that there is an intermediate temperature which will be more preferable still and will also help to reduce the compensatory effects of the higher temperatures on fruit firmness and weight loss, therefore this is something that merits investigating in the following research study.

Chapter 6. Investigating the Effects of an Intermediate Temperature of 15°C on Tomato Quality and Shelf life Compared with the Current Supply Chain Temperatures (Average 12˚C), or a Room Temperature of 23°C

6.1. Introduction

The results from Chapter 5 showed that room temperature (23°C) is preferable to supply chain temperatures during post-harvest storage of tomatoes in terms of tomato sensory opinion and lycopene accumulation; however, reductions in tomato firmness and increases in weight loss were seen. The next step is therefore to investigate whether there is an intermediate temperature that will produce tomatoes of as high sensory quality to room temperature, while also maintaining tomato firmness and reducing tomato weight loss. Temperatures of 15°C are sufficiently above CI inducing temperatures in tomatoes, and it has been shown previously by Farneti et al., (2010) that tomatoes kept at 15°C had higher sugar and lower acidity contents than those kept at 4°C, and since the sugar acid ratio has a large effect on tomato flavour, there are implications that 15°C will also improve sensory opinion. It was also shown during this study that 15°C was more optimal for preserving tomato firmness in cocktail tomatoes, and so it is therefore most likely to reduce weight loss also. Temperatures of 15°C have also been shown to allow for colour development and carotenoid accumulation and lycopene contents were almost 2-fold higher in tomatoes kept at 15˚C for ten days compared with 7˚C (Toor and Savage, 2006).

A weakness of the previous study described in Chapter 5 was that tomato shelf life did not take into account fruit shrivelling/wrinkling and therefore was not a true representation of shelf life. It is important, therefore, that this study did so and also explored the types of pathogen that tomatoes were suffering from. This study also used a different variety of round salad tomato and tomatoes were packaged as they usually would be within the UK commercial supply chain.

Aims and Hypotheses

The overall aim of this study was to evaluate the effects of an intermediate temperature of 15°C on tomato quality and shelf life compared with the current supply chain temperatures employed by ASDA, or room temperature (23°C), through a commercial supply chain from harvest through to the point of purchase, and post-sale with the consumer.

Hypotheses

- Storage at an intermediate temperature (15˚C) after harvest during pre-sale storage and room temperature during post-sale storage positively affects the tomato sensory outcome and colour development compared with supply chain temperatures during pre-sale storage and refrigerator temperatures during post-sale storage.
- Storage at an intermediate temperature (15˚C) after harvest during pre-sale storage and room temperature during post-sale storage reduces tomato weight loss and firmness loss compared with room temperatures during pre-sale and post-sale storage.
- Storage at an intermediate temperature (15˚C) after harvest during pre-sale storage and room temperature during post-sale storage positively affects the carotenoid, phenolic compound, total soluble solid and Vitamin C accumulation in tomatoes compared with supply chain temperatures during pre-sale storage and refrigerator temperatures during post-sale storage, but does not affect the pH and titratable acidity levels
- Storage at an intermediate temperature (15˚C) after harvest during pre-sale storage relieves CI and positively affects the shelf life of tomatoes compared with supply chain temperatures during pre-sale storage in terms of reducing pathogen infection, and this is positively enhanced when tomatoes are kept at room temperature compared with refrigerator temperatures during post-sale storage
- Month of harvest has an effect on one or more of the above attributes

6.2. Materials and Methods

6.2.1. Tomatoes

Four 12-kg crates of freshly harvested round salad tomatoes (*Lycopersicon esculentum* Mill), variety Dometica, at ripening stage three (López Camelo and Gómez, 2004) were collected from the grower (Mill Nurseries, Hull, UK). Two crates were stored at RT and two crates were stored at an intermediate temperature (15±1°C) (IT), in the NU-Food facility at Newcastle University, UK for the duration of the supply chain. A further two crates were labelled and sent through ASDA's supply chain until they reached a local ASDA store. The supply chain took 7 days and temperatures ranged between 8.6°C and 23°C, but were mostly around 12.3°C (SC treatment). This variation was common within commercial supply chain in this research due to the numbers of storage stages involved. Tomatoes were packaged as usual during the supply chain, and tomatoes that were kept at Newcastle University were packaged by hand on the same days using the same supermarket punnets and polypropylene wrap (Figure 75, Figure 76 and Figure 77, all Appendix B)

On day 7, tomatoes from SC and RT treatments were subjected to quality and sensory analysis. As in Chapter 5, half of the tomatoes from each initial temperature treatment were then moved to RT and the other half to F, giving 6 new temperature treatments: tomatoes that had been through the supply chain for 7 days and then moved to the refrigerator (SCF); or room temperature (SCRT); kept at intermediate temperature (15°C) for the first 7 days and then moved to refrigerator temperature (ITF) or room temperature (ITRT); kept at room temperature for the first 7 days and then moved to refrigerator temperature (RTF) or remained at room temperature throughout (RTRT). The tomatoes were kept in these new conditions until they were subjected to a second sensory testing on day 11 and a third sensory testing on day 15 (Figure 45). This study design was repeated six times across the tomato season with two replicates per month for May, July and September. Temperature and humidity were monitored using digital data loggers (EBI 20, Ebro, Xylem Analytical, Hertfordshire, UK). Average humidity for F, IT, RT and SC treatments were 97.3%, 85.5%, 49.1% and 82.3%.

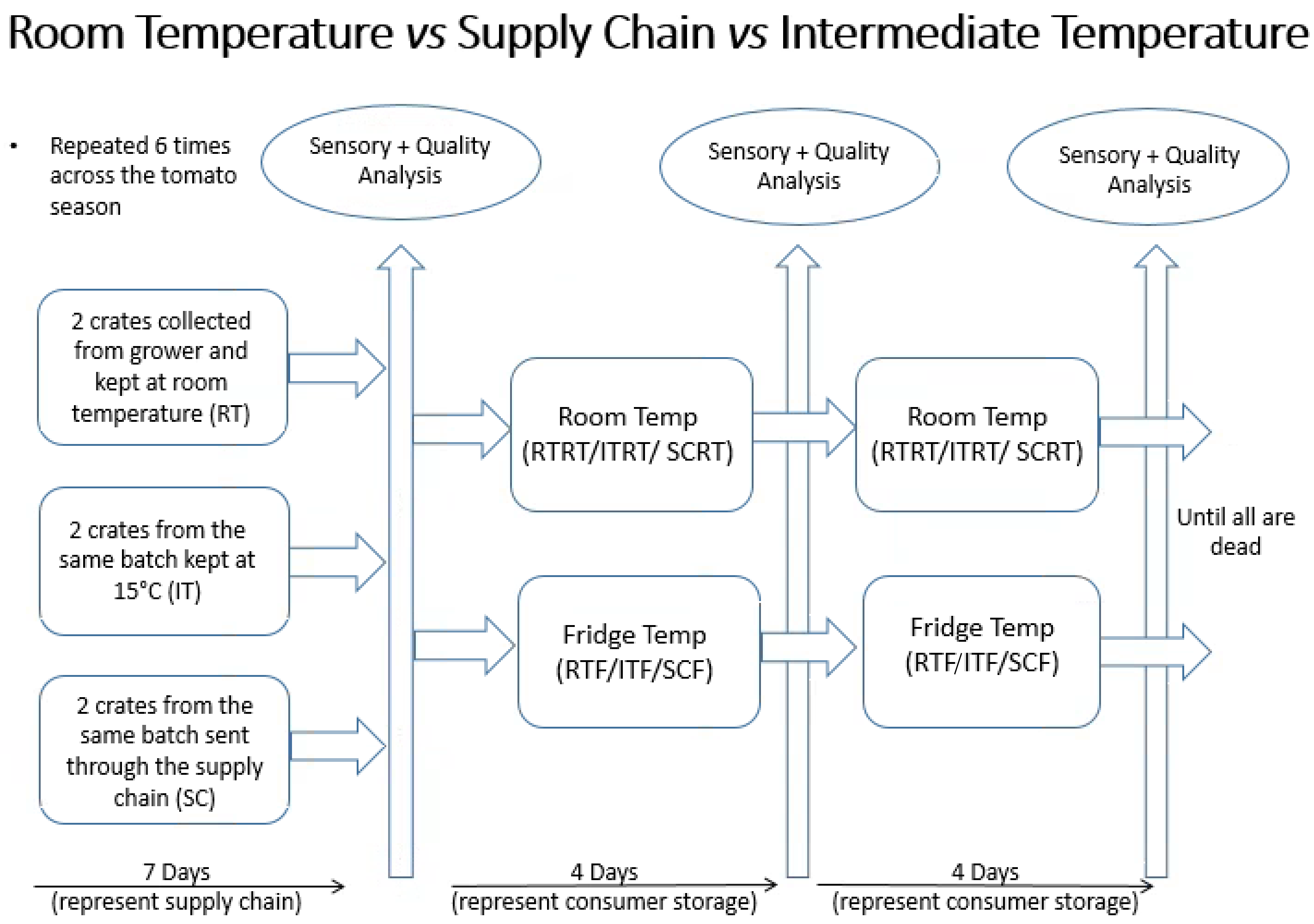

Figure 45 Flow Diagram for a Study Investigating Room Temperature (23˚C) Compared with Supply Chain Temperatures (average 12˚C) or an Intermediate Temperature of 15˚C on Tomato Quality and Shelf Life. Flow diagram shows the experimental procedure of this study

6.2.2. Sensory Testing

The sensory testing was done based on the comparative consumer profiling described in Chapter 5, using the revised questionnaire described in Chapter 3, Section 3.2.4., although an extra sensory session at day 15 was introduced to see if any further changes in tomato sensory quality were seen. On day 7 participants were presented with three samples, one from each treatment, which was repeated four times with the order of samples changing each time to avoid bias. On day 11 and 15 an absolute reference was used on each plate to provide a constant throughout the sensory research. The reference used was one eighth of a shop bought round salad tomato. Participants were asked to compare five plates of samples; plate one: SCRT and SCF tomatoes, plate two: ITF and ITRT tomatoes, plate three: RTRT and RTF tomatoes, plate four: ITF, RTF and SCF tomatoes, and plate five: ITRT, RTRT and SCRT tomatoes. Each sensory experiment had a minimum of 15 volunteers.

6.2.3. Colour

Colour was analysed as described in Chapter 5, although during this experiment more samples were used and three punnets of tomatoes (25-30 tomatoes) per treatment were analysed for colour. Colour values were only taken on day 0, 7, 11 and 15 as these were the only time points the colour equipment was available for this research.

6.2.4. Weight

Eight tomatoes from each of the three initial treatments were weighed (ae Adam equipment, Milton Keynes, UK) on day 0 and 7, and individually labelled with stickers, the weights of which were deducted from the tomato weight (8±2mg). After four days (day 11) in the new temperature treatments the now four labelled tomatoes from each treatment were re-tested for weight and weight loss (%) calculated as described in Chapter 2. This step was repeated again at day 15, and once every week until tomatoes had been seen as at the end of their shelf life. Unlike Chapter 5, these tomatoes were not also analysed for colour and were instead left in their treatments.

6.2.5. Tomato Firmness

Firmness was measured as described in Chapter 5; however in this study only three samples per treatment were used due to time constraints. Firmness readings were taken on day 0, 7, 11 and 15 and then once a week until the end of the studies. During the end of the experiments in July the Lloyd's compressor became defective and so an alternative machine (Instron) was located in the School of Dentistry, Newcastle University. The same crosshead speed and calculation were used, but the plate and penetration probe were slightly different, so this meant that the data obtained from the Instron needed to be calculated into range as the results were considerably lower. To do this, the difference between the averages of the results for tomatoes from each treatment sampled at set time points in May and July amongst the different machines was found. This difference was then added to the value obtained from the Instron machine. This was the only option available to return the results into a similar range, as no other instrumental firmness testers were accessible and the Lloyd's compressor was unfixable.

6.2.6. Carotenoid and Phenolic Compound Analysis

Carotenoid and phenolic compound analyses were as described in Chapter 5. However, during this study contents of 9-cis lycopene were also calculated using the response factor for all-trans lycopene. Samples were taken on day 0, 7, 11 and 15 and then once a week until the end of the studies.

6.2.7. Chemical Constitutes: pH, Acidity, Total Soluble Solids and Vitamin C

Analysis was as described in Chapter 5, however, in this study the tomatoes that were used for firmness were then used for analysis of chemical constitutes. Samples were taken on day 0, 7, 11 and 15 and then once a week until the end of the studies.

6.2.8. Tomato Shelf life

Analysis was as described in Chapter 5. In addition, any visible symptoms of mould or rot, or more than 15% wrinkles on the skin (1/6 of the tomato defected) were also considered, and a tomato was seen as at the end of its shelf life and removed from the experiment if it exhibited any of these. Measuring skin wrinkling was based on the method of Ayala-Zavalaa et al., (2004) who measured the overall visual quality of strawberries using a quality scale of 1-5 where 1= more than 50% of the fruit surface affected, 2= 20–50% of the fruit surface affected, 3= 5 to 20% of the fruit surface affected, 4= up to 5% surface affected, and 5= no visible signs of decay. However, rather than referring to a scale a cut-off point of 15% of more wrinkles on the tomato surface was when tomatoes were seen as of poor quality and inedible. Tomatoes were removed from the treatments and the type of pathogen attack or wrinkling was noted. Pathogens were identified referring to A Colour Atlas of Post-Harvest Diseases and Disorders (Snowdon, 1991). Wrinkly tomatoes were removed from the treatment rather than left to be observed for decay as was done in Chapter 5, as this is what the consumer/producer would do with their produce.

6.3. Statistical Analysis

Statistical significance was shown by a p-value of more than 0.05. The general linear model (GLM) was used for all the data from day zero and seven. For the data from day 11 onwards repeated measures GLM was used. Due to the large ranges of the carotenoid and phenolic data, these were logarithmically transformed for statistical analysis. Survival calculation was performed using the Kaplan-Meier Estimator (Kaplan and Meier, 1958). Normality of data was checked using probability of residuals and residuals versus fits plots. If data was not normal it was logarithmically transformed. Failing that, outliers were removed. For 9-cis lycopene three outliers were removed, one from ITF, SCF and RT treatments as these values were more than twice than the second lowest value. One outlier was removed from the results of tomatoes from ITRT treatment for β-carotene results, and three outliers were removed from the Vitamin C results for SCRT treatment for the same reason. Three outliers were removed from the sum of phenolic compounds as they were more than twice the second highest value, with two removed from ITRT treatment and one from SCRT treatment.

6.4. Results

6.4.1. Sensory Analysis

At day 7, the consumer panel found significant differences for all sensory categories between tomatoes from different treatments (all $p<0.001$) (Figure 46). Tomatoes from RT treatment were scored highest by participants for colour, ripeness, aroma, sweetness, moistness, flavour and overall opinion, while SC tomatoes received the lowest scores for these categories, and tomatoes from IT treatment were ranked in the middle of the two. For example, for aroma, moistness, sweetness and flavour tomatoes from RT treatment had between 32-40% higher scores compared to tomatoes from SC treatment, while only having between 13-23% higher scores than IT tomatoes for these categories.

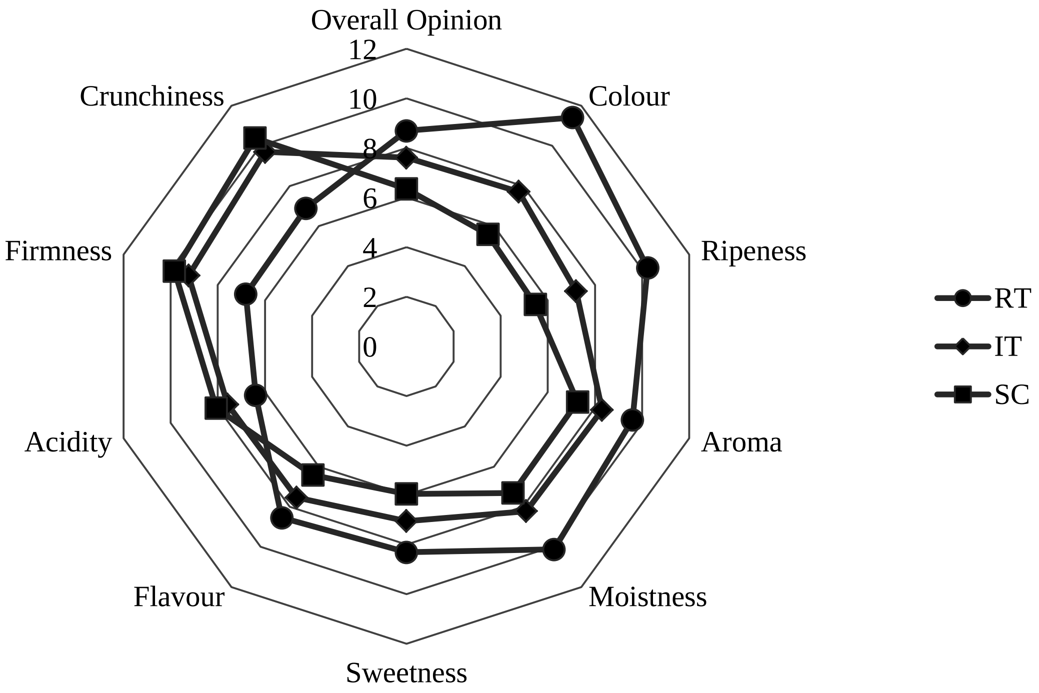

Figure 46 Mean Sensory Scores for Tomatoes kept at IT (15˚C), RT (23˚C) or SC (average 12˚C) Treatment. Fruits were kept in these treatments for 7 days. Standard error of the mean (SEM) for each sensory category ranged from 0.09 to 0.18 with an average of 0.14.

RT tomatoes were also scored 42% and 48% higher than tomatoes from IT treatment for ripeness and colour respectively. Compared to SC tomatoes, however, those from RT treatment had 87% greater scores for ripeness and were scored more than 2-fold higher in colour. For the sensory categories, firmness, crunchiness and acidity, the inverse was noted for the scores of RT and SC tomatoes, with SC tomatoes having 44%, 51% and 26% greater scores in these categories respectively (all $p<0.001$), while tomatoes from IT and SC treatments received similar scores for these categories and differed by ≤7%.

The repeated measures GLM analysis showed that month had a significant effect on sensory results, and this was seen for the sensory categories aroma, acidity, firmness and crunchiness ($p=0.007$, $p<0.001$, $p=0.005$ and $p=0.005$ respectively). During the tomato season, tomatoes harvested in July had the lowest mean scores for acidity (7.39 SE 0.28 *vs* 8.09 SE 0.71 for September and 8.79 SE 0.24 for May). Tomatoes harvested in September, however, were seen as the firmest (10.39 SE 0.13 *vs* 9.76 SE 0.27 for May and 9.40 SE 0.25 for July), while tomatoes harvested in July were scored the crunchiest (10.41 SE 0.24 *vs* 10.39 SE 0.13 for September and 10.02 SE 0.24 for May). July tomatoes were also seen to have the highest mean levels of aroma by the participants compared to tomatoes harvested during the other months (7.88 SE 0.25 *vs* 7.34 SE 0.22 for May and 6.57 SE 0.26 for September). Additionally, the GLM showed an interaction between treatment and month for sweetness, firmness and overall opinion ($p=0.007$, $p=0.007$ and $p=0.047$ respectively).

Similar to the sensory results at day 7, at day 11 tomatoes from the coldest treatment, this time SCF, were scored lower in all categories except firmness, crunchiness and acidity (Figure 47). This is illustrated in the spider plot and it can be seen that treatments that had any form of RT storage (RTF, RTRT, ITRT, and SCRT) roughly follow the same trends on the spider plot, and in comparison to scores awarded to tomatoes from SCF, these results were much higher on the plot, in particular for overall opinion, colour and ripeness, but much lower for firmness and crunchiness.

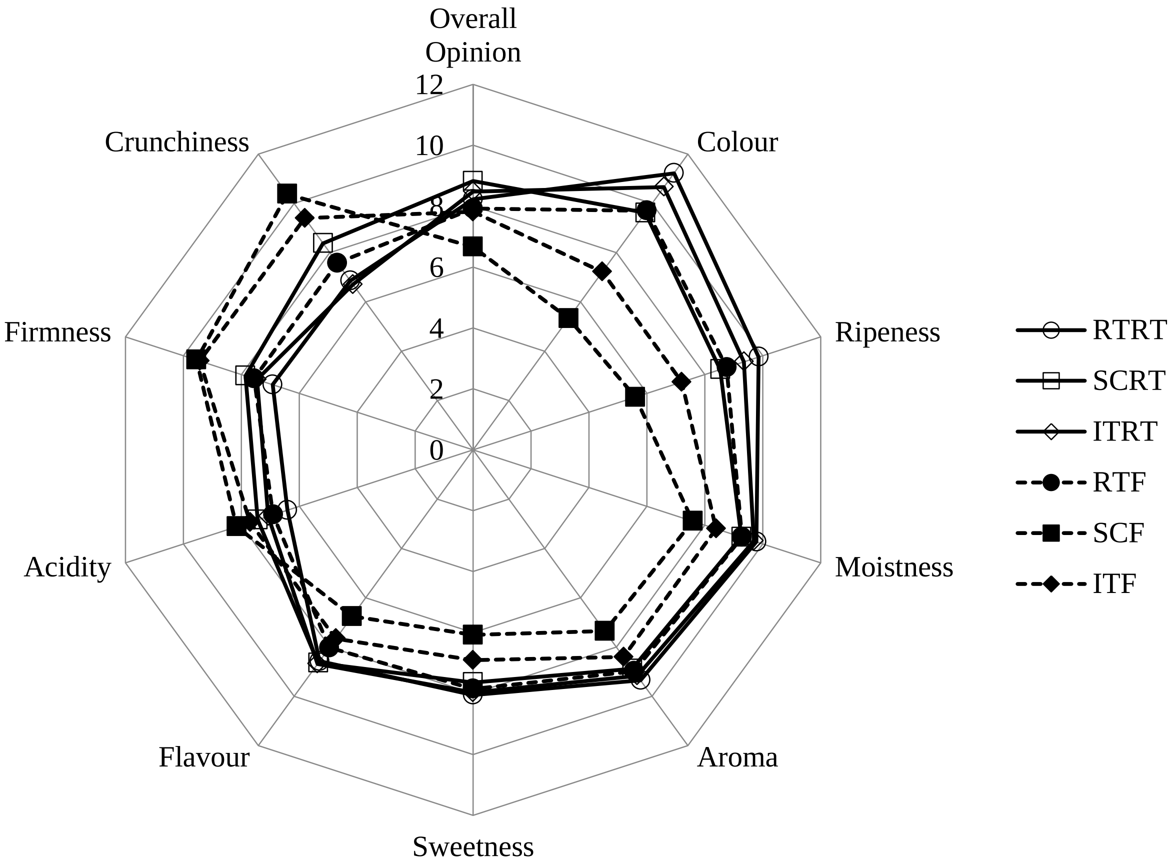

Figure 47 Mean Sensory Scores of Tomatoes at Day 11. Fruit were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for four days of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Standard error of the mean (SEM) for each sensory category ranged from 0.15 to 0.26 with an average of 0.20.

The consumer scores for tomatoes from ITF treatment were in-between the scores awarded to tomatoes from SCF, and those from the other treatments for the majority of the sensory categories. This is a similar outcome to the results at day 7, where tomatoes from the second coldest treatment IT had scores that were in-between the scores awarded to tomatoes from SC and RT.

At day 11 scores for acidity, firmness and crunchiness were much greater in the coldest treatment SCF, most noticeably when comparing crunchiness scores for SCF with those for RTRT and ITRT which were 51% and 55% greater in tomatoes from SCF. In general, for these categories the largest difference was seen between SCF and RTRT treatments, with SCF tomatoes being 27%, 38% and 51% greater in acidity, firmness and crunchiness than those from RTRT treatment respectively. Very small differences between scores were observed among tomatoes from treatments ITF and SCF, most prominently for firmness which had only 1% difference between consumer opinions, while acidity and crunchiness were different by 6% and 10% respectively. For moistness, aroma, sweetness, flavour and overall opinion there was between 10-15% difference between ITF and SCF tomatoes, however, larger differences were seen between scores for ripeness and colour, for which SCF tomatoes were given 20% and 26% lower scores respectively.

For treatments that had any form of RT exposure either during pre-sale or post-sale storage (RTF, RTRT, ITRT and SCRT treatments) there was less than 20% variation between scores. This was most prominent for moistness, aroma and sweetness categories in which there was less than 5% variation between tomatoes from these four treatments. Most interestingly, for all the sensory categories, except for acidity and firmness, there was less than 5% difference between the consumer scores for tomatoes from ITRT and RTRT. For acidity and firmness however tomatoes from ITRT were seen to be 10% and 8% higher than those from RTRT.

Out of the treatments that had any form of RT storage, SCRT tomatoes were scored the highest for acidity, firmness and crunchiness. This was most noticeable when comparing scores for acidity and firmness for tomatoes from SCRT with those from RTRT which were 14% and 12% greater in tomatoes from SCRT respectively. For crunchiness, SCRT tomatoes were 18% and 20% higher than those from RTRT and ITRT, but only 11% greater than tomatoes from RTF.

For the most important sensory category overall opinion, SCF tomatoes were scored the lowest. This was by 19%, 21% and 24% when compared with tomatoes from RTRT, ITRT and SCRT respectively, and by 15% and 16% for tomatoes from ITF and RTF treatments respectively. Interestingly, the overall opinion scores for all the other treatments were very similar and had four percent or less difference between them, supporting the concept that refrigerator storage can exacerbate the deterioration of taste already apparent from 7 days SC storage.

By day 15 there is not a substantially large change from the sensory outcome that was seen at day 11 (Figure 48). However, one distinguishable change was the results for RTF tomatoes which were not as similar to those from SCRT treatment for colour, ripeness and aroma, and the sensory results for SCRT tomatoes were similar to the results of RTRT and ITRT tomatoes. Disregarding treatments RTRT, SCRT and ITRT, which are grouped very tightly together on the spider plot, the sensory results for ITF, RTF and SCF treatments for overall opinion, colour, ripeness, moistness, aroma, sweetness and flavour seem to progress in order of temperature, from coldest to warmest, with the results for SCF tomatoes being the lowest, followed by ITF tomatoes and then RTF tomatoes.

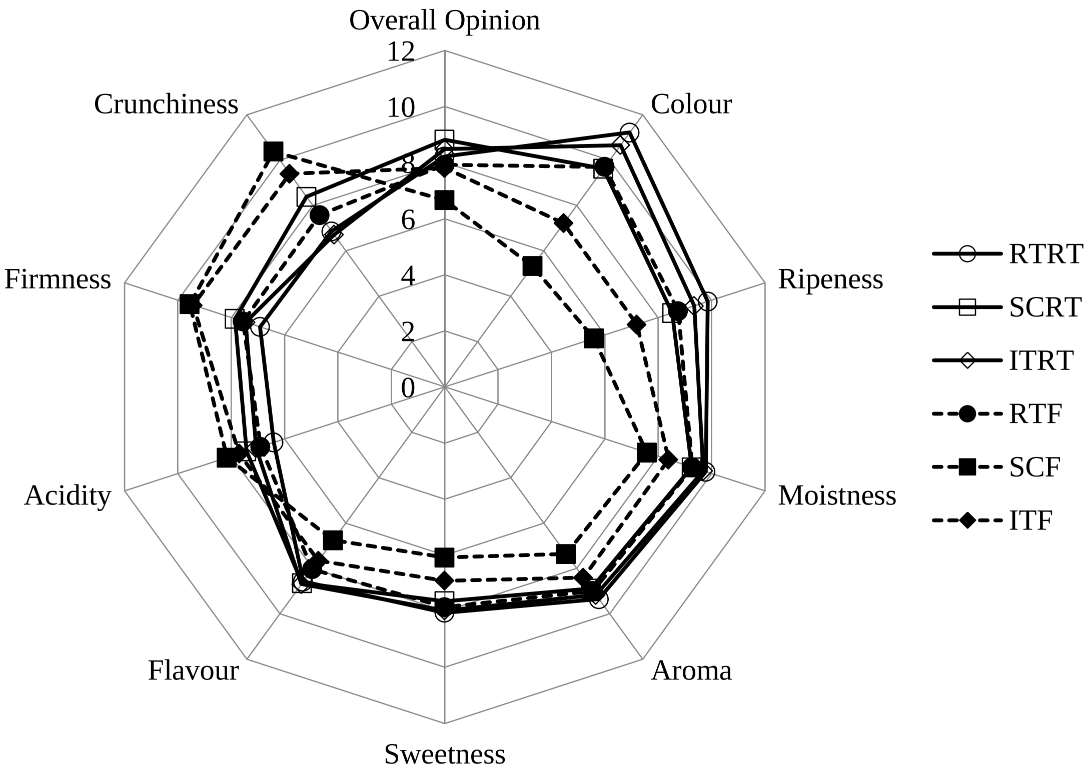

Figure 48 Mean Sensory Scores of Tomatoes at Day 15. Fruit were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for eight days of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Standard error of the mean (SEM) for each sensory category ranged from 0.15 to 0.24 with an average of 0.19.

Similar to the outcome at day 11, sensory scores for SCF tomatoes were the lowest in all categories bar acidity, firmness and crunchiness. ITF tomatoes at day 15 received the highest scores for acidity; however this was by only 5% more than those from SCF treatment. As was seen at day 11, only small differences were seen between SCF and ITF tomatoes for the sensory categories moistness, aroma, sweetness and flavour (≤18%). Whereas for colour and ripeness, larger differences between SCF and ITF treatments were seen with ITF tomatoes scoring 31% and 28% higher in these categories respectively. Moreover, ITF tomatoes had a 19% higher overall opinion score than those from SCF treatment.

In comparison to tomatoes from RTF, RTRT, ITRT and SCRT treatments, tomatoes from SCF were 25-34% more firm, and 29-42% more crunchy at day 15. The largest differences seen between SCF tomatoes and those that had any form of RT storage was for the sensory category colour, where RT tomatoes were significantly higher, most noticeably ITRT, RTRT and SCRT, which by day 15 were seen by the participants as 83%, 82% and 79% more red in colour respectively. Scores for ripeness were also much higher for ITRT, RTRT and SCRT by 64%, 68%, and 59% respectively. Tomatoes from RTF, however, by day 15 were not as different from SCF by such a large extent, and in comparison to those that received RT post-sale storage, were 53% and 47% higher in colour and ripeness respectively.

On the spider plot the results for ITRT, SCRT and RTRT tomatoes are grouped very tightly together, and there is ≤10% variation between treatments for all sensory categories. This was especially noticed for aroma and colour in which sensory scores differed by less than 2% between treatments. Moreover, RTRT and ITRT tomatoes were the most similar in scores and there was ≤6% variation between scores for all categories, most noticeably for crunchiness, ripeness and overall opinion with only 0.1%, 0.5% and 0.5% difference respectively.

As seen at day 11, scores for overall opinion were much lower for SCF tomatoes compared with all the other treatments. Compared with tomatoes that had any form of RT storage (RTF, ITRT, RTRT and SCRT), tomatoes from SCF treatment had 32-39% lower scores, and ITF tomatoes were also preferred over those from SCF treatment by 19%.

Month (all p<0.001, except p=0.006, p=0.025 and p=0.002 for overall opinion, acidity and firmness respectively) pre-sale treatment (all p<0.001) and post-sale treatment (all p<0.001) were all found to have a significant effect on all sensory categories at day 11 and 15, suggesting that a large amount of variation in tomato quality was seen throughout the season. A significant interaction was seen between month and pre-sale treatment for firmness and moistness (p=0.029 and p=0.012 respectively), and a significant interaction was seen between pre-sale treatment and post-sale treatment for all sensory categories (p<0.001), except for acidity (p=0.354).

To further demonstrate the significant effect of post-sale treatment on sensory outcome Figure 49 was created in which sensory scores from day 11 and 15 were grouped according to their post-sale treatment. It is clear that there is high similarity between the sensory scores at day 11 and 15 within post-sale treatments. This figure also highlights the effects of F treatment on tomato sensory opinion, as all treatments which had post-sale F treatment have lower scores in all the sensory categories asides from acidity, firmness and crunchiness, regardless of their pre-sale storage.

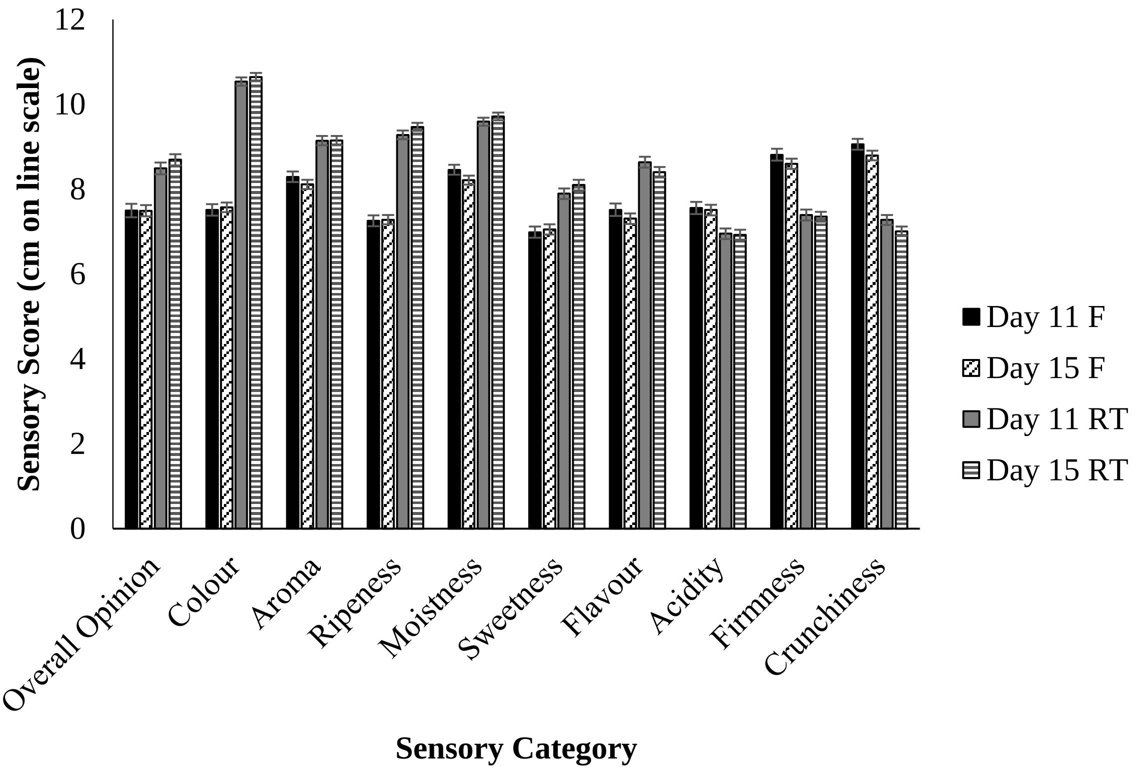

Figure 49 Mean Sensory Scores at Day 11 and 15 of Tomatoes from Post-sale Storage at F or RT. Fruits were kept at either F (5˚C) or RT (23˚C) for four (day 11) or eight (day 15) days. Bars represent standard error.

In summary, at day 7 RT tomatoes had the highest tomato quality in terms of overall sensory opinion, although IT treatment did improve tomato quality compared to tomatoes from SC treatment which were scored the lowest. At day 11 and 15, SCF tomatoes were the consumers' least favourite, while tomatoes that had any form of RT storage were scored higher. At day 11 ITF tomatoes were scored between SCF and all the other tomatoes for overall opinion, while at day 15 ITF tomatoes had overall opinion scores which were similar to tomatoes that had any form of RT storage, suggesting that IT pre-sale treatment does improve tomato quality when compared with SC pre-sale treatment.

6.4.2. Colour

The largest extent of change for the L, a* and b* values of tomatoes was observed during the first seven days of storage, where a decline in L and b*, and an increase in a* values was seen (Figure 50, Figure 51 & Figure 52). By day 7 significant differences were seen between treatments, with SC tomatoes having the highest L and b* values, and IT having the largest a* values, although only by a small amount (all $p<0.001$). Little variation was seen between tomatoes from IT and SC treatments for L, a* and b* values with ≤5% amongst them.

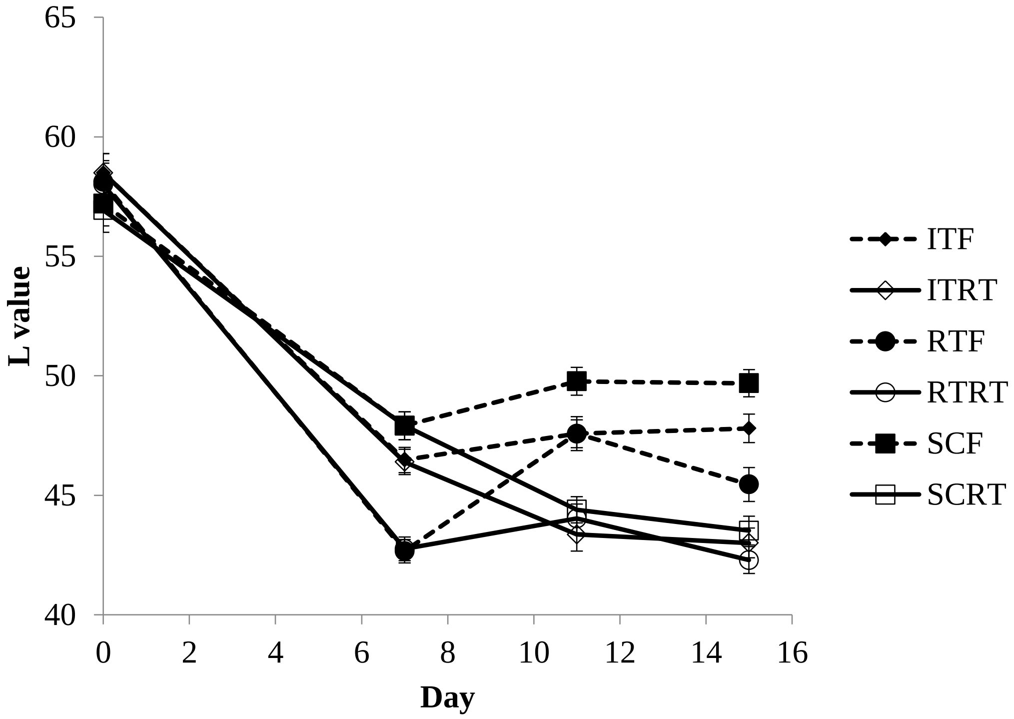

Figure 50 Mean L Values for Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

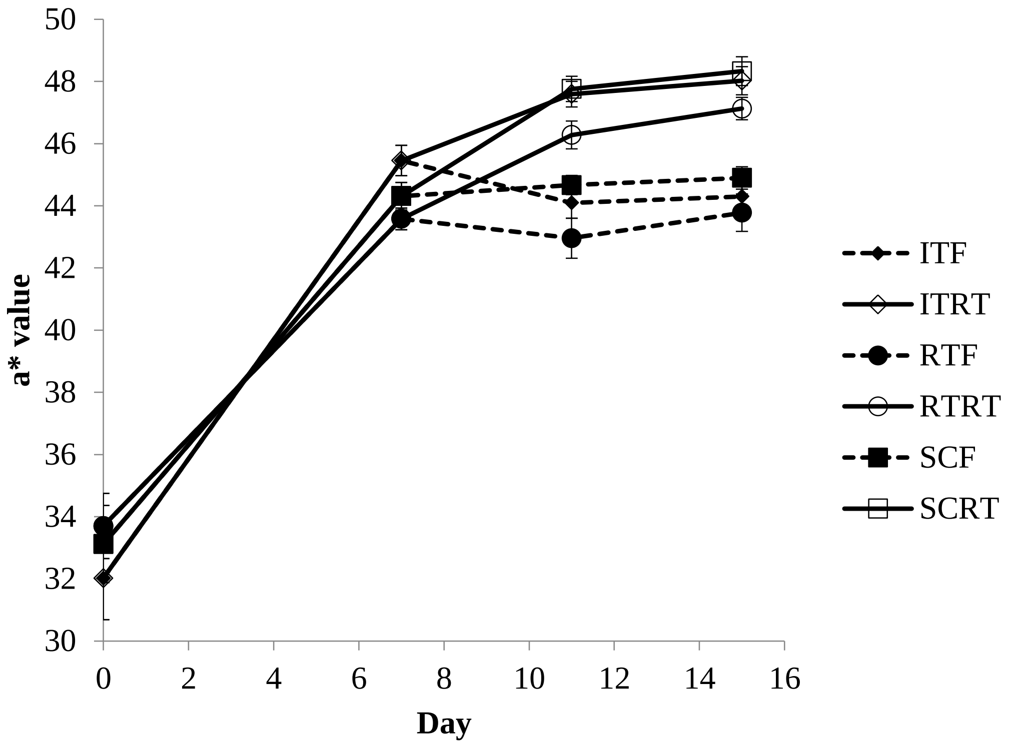

Figure 51 Mean a* Values for Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

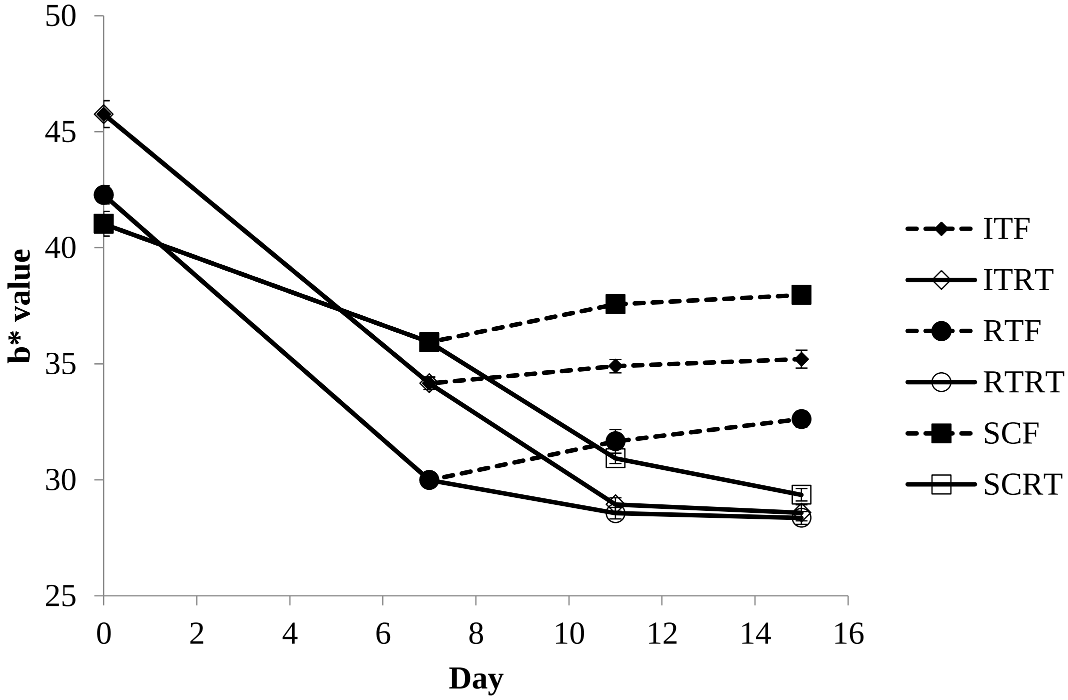

Figure 52 Mean b* Values for Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C) and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

Month was found to have a significant effect on L, a* and b* values for scores recorded at day 7 ($p<0.001$, $p<0.001$ and $p=0.045$ respectively) with these values being higher in tomatoes harvested in May, and L and a* values being lower in tomatoes harvested in July compared to the rest of the tomato season (Table 17). An interaction was seen between month and treatment for all colour values ($p<0.001$ for L, $p=0.015$ for a* and $p<0.001$ for b*).

Table 17 Mean Colour Values at Day 7 for Tomatoes Harvested in May, July and September. Colour was evaluated as L, a* and b* value. Numbers in brackets represent standard error.

	Colour Value		
Month	**L**	**a***	**b***
May	51.51 (0.46)	49.71 (0.39)	34.24 (0.44)
July	44.06 (0.79)	43.06 (0.48)	33.23 (0.75)
September	44.01 (0.67)	42.52 (0.46)	33.34 (0.55)

Between day 7 and 15 changes in L, a* and b* values reduced and levels became relatively stable (Figure 50, Figure 51 & Figure 52). This was most noticeable in L and a* values, while a decline in b* values was seen in tomatoes kept at ITRT, RTRT and SCRT between day 7 and 11. This reduction, however, was slowed between day 11 and 15. Tomatoes that were exposed to subsequent refrigerator storage (ITF, RTF and SCF) all had higher L values than tomatoes that were kept at post-sale RT storage (ITRT, RTRT and SCRT), while the inverse was seen for a* values. For b* values, tomatoes from ITF and SCF had higher values than tomatoes from any of the other treatments. There was an overlap between the b* value results for tomatoes from RTF and SCRT treatments at day 11, however, by day 15 the b* value of tomatoes from SCRT treatment had continued to decrease and that of RTF tomatoes increased slightly.

Pre-sale treatment (IT, RT or SC) had a significant effect on the L and b* values recorded at day 11 and 15 (both p<0.001), while post-sale treatment was only found to have a significant effect on b* (p=0.024). Month was found to have a significant effect on L and a* values (both p<0.001), with tomatoes harvested in May having higher L and a* values, while those with a harvest date in July had lower L and a* values (Table 18). Day only had a significant effect on a* values (p=0.001). However, an interaction was seen between day and pre-sale treatment for b* values (p=0.011) with tomatoes from RT pre-treatment having an increase in b* value over time, while an interaction between day and post-sale treatment was seen for L (p=0.005), and b* (p=0.004) with tomatoes that received post-sale storage in the refrigerator (ITF, RTF and SCF) having higher values for these colour measurements. An interaction between pre-sale and post-sale treatment was seen for L and b* values (both p<0.001), but not for a* values (p=0.205).

Table 18 Mean Colour Values at Day 11 and 15 for Tomatoes Harvested in May, July and September. Colour values L and a* are shown. Number in brackets represent standard error.

		Colour Value	
Day	**Month**	**L**	**a***
11	**May**	51.58 (0.45)	50.11 (0.45)
	July	42.55 (0.72)	43.71 (0.44)
	September	43.12 (0.82)	43.91 (0.52)
15	**May**	50.42 (0.32)	49.98 (0.41)
	July	43.40 (0.77)	44.05 (0.52)
	September	43.31 (0.73)	45.33 (0.55)

Visual colour differences were also noticed in the supernatant of tomatoes from different treatments, with those from post-sale RT treatment being dark orange in colour and those from post-sale F treatment being much lighter yellow in colour (Figure 78, Appendix B).

In summary, tomato quality in terms of external colour development was highest in tomatoes from RT treatment at day 7 and lowest in tomatoes from SC treatment. IT treatment reduced colour development compared with RT treatment. Tomatoes that were exposed to post-sale treatment F reduced colour development with higher L values and b* values and lower a* values, and this was most prominent in tomatoes from SCF treatment, followed closely by ITF treatment, suggesting that IT pre-sale treatment and post-sale F treatment reduces colour development compared with those from RTF. However, post-sale RT treatment caused colour development to continue and tomatoes from ITRT, RTRT and SCRT treatments were all of very similar L, a* and b* values by day 15.

6.4.3. Weight Loss (%)

A clear difference can be seen between the weight loss values of tomatoes that were exposed to post-sale F treatment compared with those that were kept at post-sale RT treatment, with those from ITRT, RTRT and SCRT treatments losing much more weight than those from ITF, RTF and SCF treatments (Figure 53). In fact, the weight loss seen in tomatoes from post-sale F treatment is much more stable and appears to be at a constant low increase, in comparison to tomatoes from post-sale RT treatments which all have a mostly linear incline as the study progressed. At day 7 tomatoes from the warmest treatment RT had over 3-fold greater weight loss than those from SC treatment and 87% greater weight loss than those from IT treatment respectively, and treatment was found to have a significant effect on weight loss at this time point ($p<0.001$). Month was also found to have a significant effect ($p=0.003$) and by the end of the study tomatoes harvested in July had the greatest weight loss. A significant interaction was also found between month and treatment ($p=0.016$).

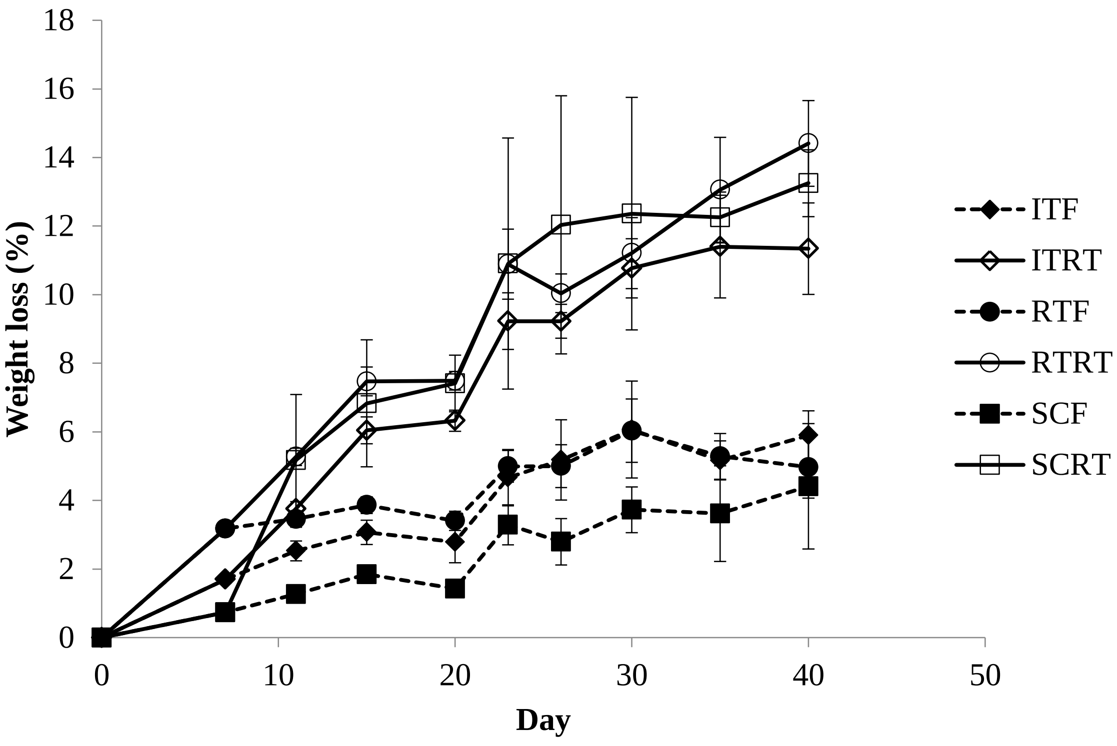

Figure 53 Mean Weight Loss (%) of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

Between day 11 and 40 the weight of tomatoes from all treatments dropped. Tomatoes from ITRT, RTRT and SCRT had on average 92%, 113% and 279% greater weight loss than tomatoes from their colder counterpart treatments ITF, RTF and SCF respectively, and pre-sale ($p<0.001$) and post-sale treatment ($p=0.003$), and their interaction ($p=0.034$) were all found to be statistically significant factors on tomato weight loss. By the end of the study, tomatoes from RTRT had the greatest weight loss, and those from SCF had the lowest.

Similar to the GLM output for the day 7 weight loss data, month was also found to have a significant effect on weight loss for the data from day 11 onwards ($p=0.006$). No data was recorded at day 40 for tomatoes harvested in September and kept at RTF and RTRT, as after day 35 these tomatoes became decayed and were removed to avoid contamination.

In summary, quality in terms of weight loss was lowest in tomatoes from RT treatment at day 7, and highest in tomatoes from SC treatment. IT treatment reduced weight loss compared to RT, but not to the extent that SC treatment did. Post-sale treatment at F reduced weight loss compared to post-sale RT treatment, and levels were still the lowest during post-sale storage in the coldest treatment. Out of the tomatoes that received post-sale RT treatment, ITRT had the lowest weight loss by the end of the study, suggesting that pre-sale IT treatment followed by post-sale RT treatment can reduced weight loss compared to the other pre-sale treatments.

6.4.4. Firmness: Deformation and Penetration of Whole Fruit

6.4.4.1 Deformation

Tomatoes from all treatments showed reduced firmness in terms of deformation as the study progressed (Figure 54). At day 7, treatment was found to have a significant effect on deformation values (p=0.001) and the coldest treatment SC had the greatest deformation value, and the warmest treatment RT had the lowest, while tomatoes from IT treatment were in-between the two. As expected the rate of decline was higher in tomatoes that experienced post-sale treatment at RT (ITRT, RTRT and SCRT), while post-sale treatment F was found to reduce the rates of deformation firmness losses in SCF and ITF tomatoes, although tomatoes from RTF treatment did have a deformation value which was similar to those from ITRT, RTRT and SCRT treatments, presumably due to the influence of 7 days RT pre-sale storage.

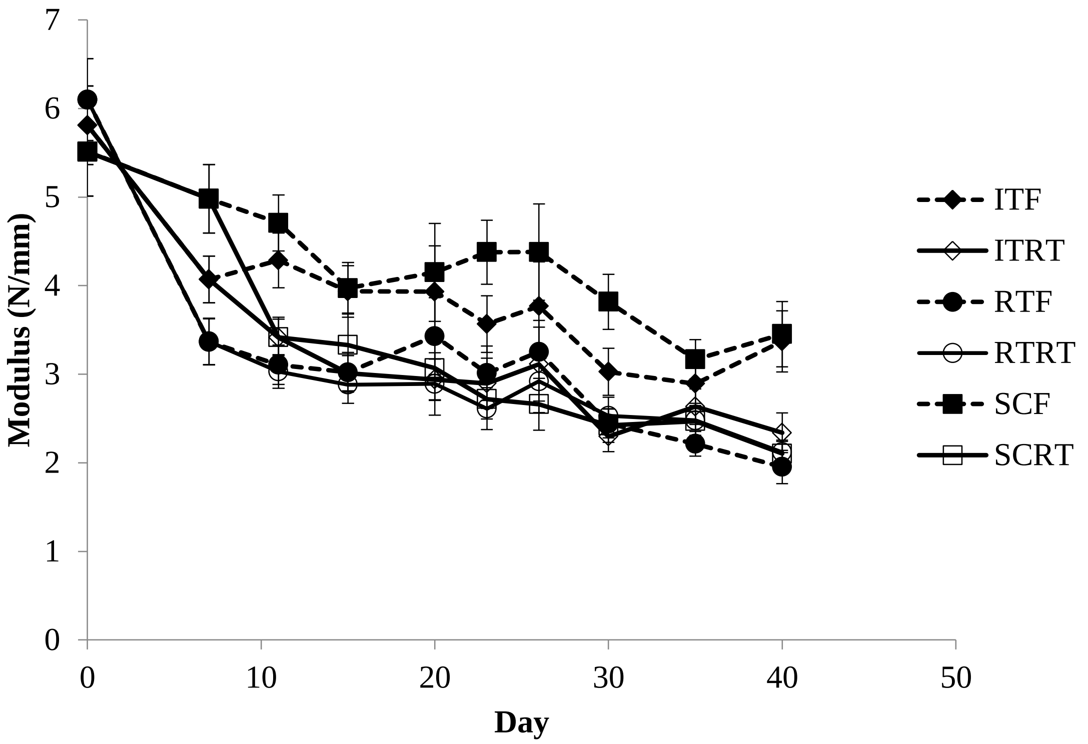

Figure 54 Mean Firmness (Deformation) of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

Tomatoes from the coldest treatment SCF were the firmest and had the largest deformation values, followed closely by tomatoes from ITF, and by the end of the study these tomatoes were considerably firmer than tomatoes from all the other treatments (Figure 54). Tomatoes harvested in July were firmer than tomatoes harvested in May and September, except for a few occasions, and this may have been why a statistically significant effect of month was seen ($p=0.042$). Pre-sale ($p=0.013$) and post-sale ($p=0.001$) treatments were found to have a statistically significant effect on deformation values from day 11 onwards and a significant interaction was also found between pre-sale and post-sale treatments ($p<0.001$).

Data was not recorded for deformation and penetration of tomatoes harvested in September and stored at ITF, RTF and SCF at day 40 as tomatoes from these treatments had all died, and there were not enough remaining sample for analysis.

6.4.4.2. Penetration

Penetration values decreased as the study progressed in tomatoes from all treatments (Figure 55), and day was found to have a significant effect on tomato penetration ($p<0.001$). Similar to deformation values, at day 7 the warmest treatment RT produced the least firm tomatoes in terms of penetration, and SC treatment produced the most firm, but this time IT tomatoes were very similar in terms of penetration to SC, rather than having a value that is between the SC and RT. At day 7 significant effects of treatment ($p<0.001$) and month ($p<0.001$) was found, and also an interaction between the two ($p=0.003$).

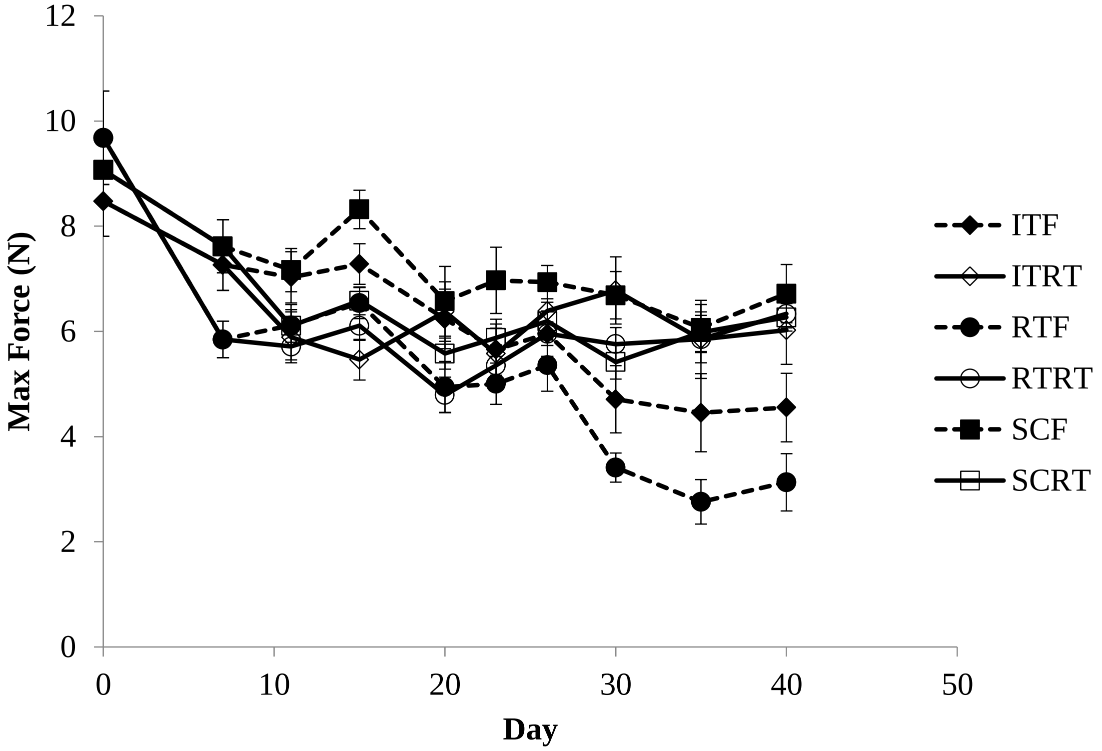

Figure 55 Mean Penetration (N) Values of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

Between day 7 and 40 the results for the penetration values did not follow the same trends as those that were seen for deformation. Tomatoes from SCF treatment were the most firm, and the penetration value stayed relatively stable, whereas for the other post-sale F treatments ITF and RTF, a drop in penetration value was seen, most noticeable from day 25, and by the end of the study tomatoes from RTF had the lowest penetration value, and values for tomatoes from ITF treatment were also lower than tomatoes from the other treatments. For the tomatoes from RT post-sale treatments, after a relatively steep decline in max force value between day 0 and 11, values remained relatively stable although some fluctuation is seen. However, from day 23 onwards the results for ITRT, RTRT and SCRT tomatoes are very similar, and by day 35 and 40 they were level with the penetration value of tomatoes from SCF.

The repeated measures GLM analysis showed post-sale treatment to have a significant effect on penetration value ($p<0.001$), while pre-sale treatment did not ($p=0.301$), although an interaction between the two was found ($p<0.001$). An interaction was also noticed between day and post-sale treatment ($p<0.001$). Month was not found to have a statistically significant effect on penetration ($p=0.280$). Results were not recorded for tomatoes from ITF, RTF and SCF at day 20 in September, as it was at this point that the Lloyd's Compressor would not work.

In summary, tomato quality in terms of deformation was highest in tomatoes from SC treatment and lowest in tomatoes from RT treatment at day 7. IT treatment reduces firmness losses in terms of deformation compared with tomatoes from RT treatment. IT treatment also reduced firmness losses in terms of penetration compared with RT treatment, and at day 7, the penetration values of tomatoes from IT were very similar with those of tomatoes from SC treatment, while tomatoes from RT were lower. Post-sale F treatment continued to reduce firmness losses in terms of deformation in tomatoes from SCF and ITF, while tomatoes that had any form of RT storage were considerably less firm, suggesting that pre-sale IT treatment combined with post-sale F treatment preserves tomato firmness compared to RTF. Post-sale F treatment, however, had negative effects on fruit penetration values of tomatoes that had previously been stored at RT and IT, while tomatoes from SCF had the highest penetration values, suggesting that IT treatment does not improve tomato firmness in terms of penetration when exposed to subsequent F storage. Moreover, by the end of the study the penetration scores of tomatoes from ITRT, SCRT, RTRT and SCF were very similar.

6.4.5. Carotenoids

Unfortunately due to problems with the freeze drier, just over half of the freeze dried samples were lost during this study, which meant numbers of carotenoid and phenolic samples were lower than anticipated. However, at least one sample per time point in each month was recovered.

The GLM data revealed that at day 0 significant differences were seen between the all-trans lycopene, 9-cis lycopene and β-carotene levels amongst the sample months ($p=0.041$, $p=0.003$ and $p=0.005$ respectively), however by day 7 a significant effect for month was only seen for all-trans lycopene levels ($p=0.020$). At day 7 treatment was found to have a significant effect on the contents of all-trans and 9-cis lycopene ($p=0.009$ and $p=0.030$ respectively), with tomatoes from RT treatment having 67% and 24% greater all-trans (Figure 56) and 9-cis lycopene (Figure 57) values than those from SC treatment, and 34% and 55% higher content respectively than tomatoes from IT treatment. However, at day 7 no significant differences were seen between the β-carotene or lutein contents of tomatoes from different treatments ($p=0.415$ and $p=0.890$ respectively) (Figure 58 & Figure 59).

6.4.5.1 All-trans lycopene

For tomatoes from all treatments an increase in levels of all-trans lycopene is seen between day 0 and day 40 (Figure 56). The largest increases were seen in tomatoes kept at RTRT treatment by close to 4-fold, and these tomatoes had the highest all-trans lycopene content throughout the study. All-trans lycopene levels were very similar amongst tomatoes from ITRT and SCRT treatment at all sample days, and the only considerable difference was seen at day 40, where a larger decrease in all-trans lycopene content was seen for SCRT tomatoes.

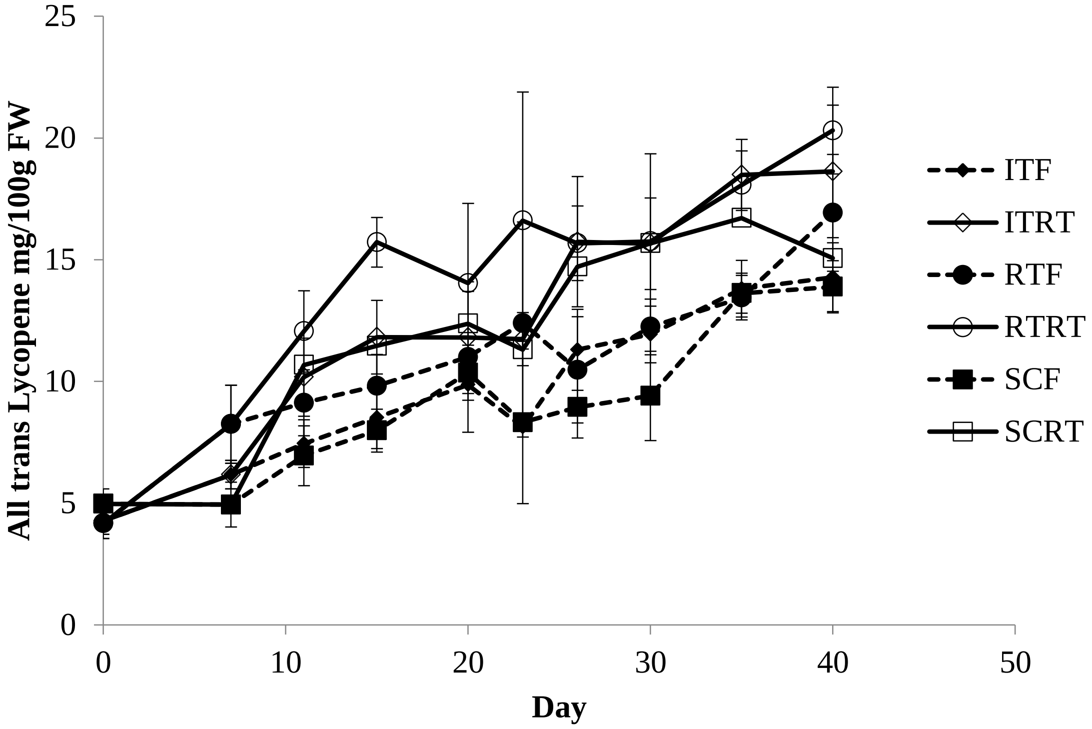

Figure 56 Mean All-trans Lycopene Content of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

For the tomatoes that were exposed to subsequent F storage, rates in all-trans lycopene accumulation were much lower, most noticeably in tomatoes from ITF and SCF treatments, while RTF tomatoes had all-trans lycopene levels that were similar to tomatoes from SCRT treatment, especially between day 0 and 23. Interestingly, by day 40, tomatoes from RTF treatment resulted in higher all-trans lycopene content than those from SCRT treatment, and this may have occurred as a result of there being a large proportion of the samples lost during freeze drying (55%), and may not actually be a true representation of the results that should have been seen at day 40 for RTF tomatoes, which would most likely have been lower than SCRT tomatoes due to the general negative effect of F treatment on all-trans lycopene accumulation that can be seen from Figure 56.

A decline in all-trans lycopene levels was seen at day 23 for tomatoes from ITF, ITRT, SCF and SCRT. This may have been since a relatively low number of samples were recovered from the freeze drier for this time point (and this can be seen from Table 56, Appendix G, for results with no standard error shown), so a smaller variation in all-trans lycopene may have been found, giving a lower mean at this sample day.

By the end of the study tomatoes that had been kept at ITRT, RTRT and SCRT treatments had larger proportions of all-trans lycopene than those from the colder counterpart treatments ITF, RTF and SCF by 30%, 20% and 8% respectively. However, larger differences amongst these treatments were seen earlier in the study. For example, at day 15 tomatoes from RTRT treatment had 60% greater levels of all-trans lycopene than those from RTF, while at day 26 SCRT tomatoes had 65% greater contents than tomatoes from SCF, and for ITRT, the largest differences were seen between ITF tomatoes at day 35 by 30%.

The repeated measures GLM analysis of the all-trans data from day 11 onwards showed that only day and post-sale treatment were found to have a significant effect on all-trans lycopene levels (both $p<0.001$). Month was not found to have a significant effect on all-trans lycopene content ($p=0.076$).

6.4.5.2. 9-cis Lycopene

Similar to the results seen for all-trans lycopene contents, the levels of 9-cis lycopene also increased between the beginning and end of the study (Figure 57), and tomatoes from RTRT treatment resulted in the highest 9-cis lycopene contents by the finish. Large increases in 9-cis lycopene contents were noticed for ITRT, RTRT, SCF and SCRT tomatoes between day 7 and 11 by 55%, 64%, 74% and 164% respectively, while contents in tomatoes from RTF and SCF treatments did not rise so dramatically (6% and 31% respectively). Both RTRT and ITF tomatoes had a decrease in 9-cis lycopene levels at day 20, while tomatoes from ITRT peaked. At day 23 there was a large increase in the 9-cis lycopene contents of RTRT tomatoes, while those in tomatoes from SCF and SCRT declined slightly. From day 26 onwards a general trend is seen for tomatoes from all treatments and 9-cis lycopene content increases linearly for most treatments.

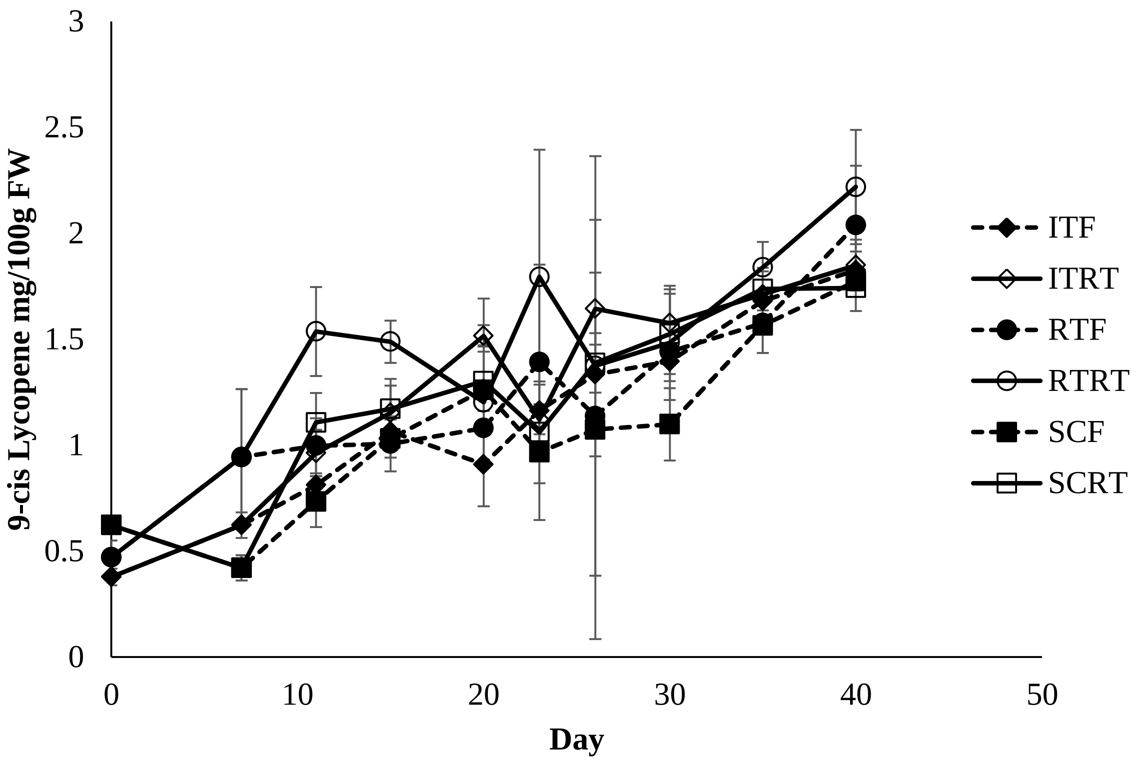

Figure 57 Mean 9-cis Lycopene Contents of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

As was observed from the statistical outcome for all-trans lycopene content, the repeated measures GLM data showed day and post-sale treatment to have a significant effect on 9-cis lycopene contents between day 11 and 40 ($p<0.001$ and $p<0.001$ respectively). In contrast, a statistically significant interaction between day and post-treatment was also observed ($p=0.025$). No significant effect of harvest month on 9-cis lycopene content was found ($p=0.171$)

6.4.5.3. β-carotene

A general trend is also seen for β-carotene levels in tomatoes from all treatments, with there being an incline as the study progressed (Figure 58). At day 7, neither month ($p=0.071$), treatment ($p=0.415$) or their interaction ($p=0.112$) were found to have a significant effect on β-carotene levels.

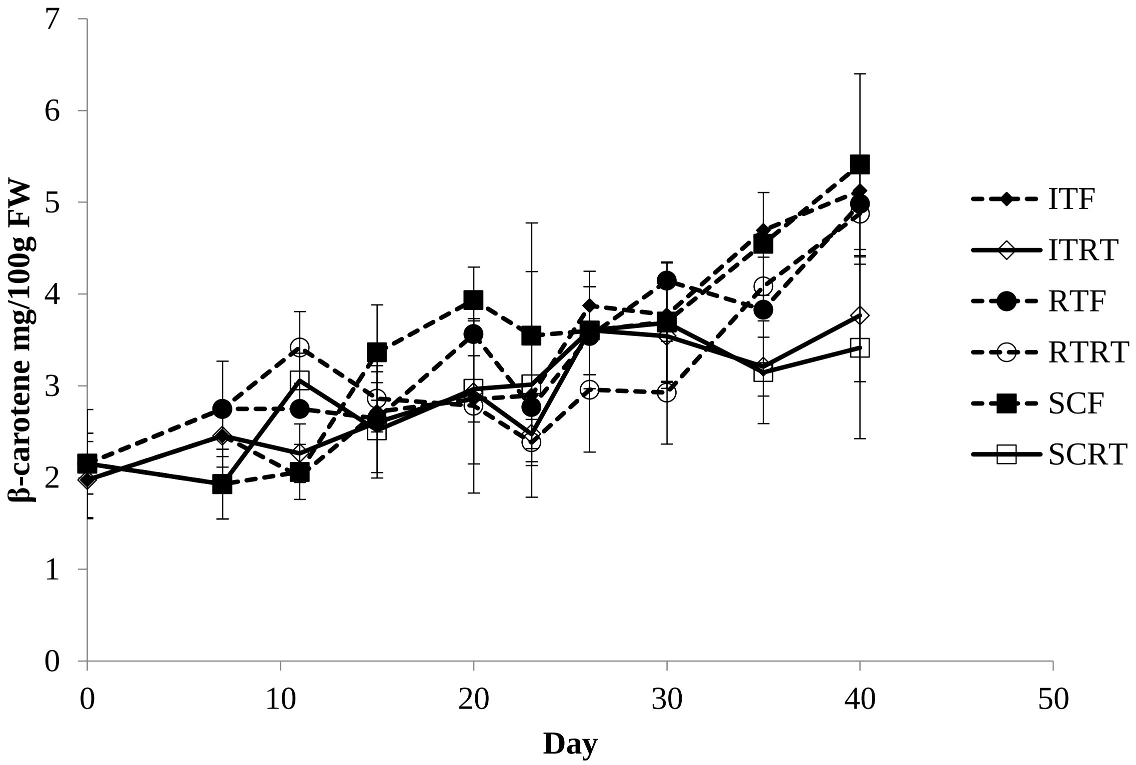

Figure 58 Mean β-carotene Content of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

In contrast to the lycopene results, tomatoes that received RT storage during the post-sale phase of this study did not result in the highest contents in terms of β-carotene, most likely due to the conversion of β-carotene to lycopene associated with increased ripening, and instead the largest levels were recorded in tomatoes from ITF, RTF, RTRT and SCF, and ≤ 11% variation was seen between tomatoes from these treatments.

For tomatoes from RTRT and SCRT treatments a large incline in β-carotene was seen between day 7 and 11 by 24% and 59% respectively. Interestingly between day 7 and 11 the levels of β-carotene in tomatoes from ITF and SCF treatments were relatively stable. Peaks were seen for RTF and SCF tomatoes at day 20, which declined again at day 23, but continued to increase from then onwards until the end of the study. This was also seen for tomatoes from all the other treatments except ITRT and SCRT which declined slightly at day 35, but increased until the end of the study.

Similar to the statistical outcome for the 9-cis lycopene data, the repeated measures GLM analysis showed day and post-sale treatment to have a significant effect on β-carotene levels ($p<0.001$ and $p=0.009$ respectively), and an interaction between day and post-sale treatment was also seen ($p=0.002$). As was seen for both types of lycopene, no significant effect of month was recorded for β-carotene levels ($p=0.719$).

6.4.5.4. Lutein

Compared to the mean all-trans lycopene, 9-cis lycopene and β-carotene contents, lutein levels appear relatively stable and do not appear to increase or decrease in a certain direction throughout the study, although there is a large proportion of fluctuation (Figure 59). At day 7, neither month (p=0.165), treatment (p=0.890) nor their interaction (p=0.828) had a significant effect on lutein contents. By the end of the study, tomatoes from ITRT and RTRT treatments have the lowest levels of lutein, while tomatoes from the other treatments have similar lutein contents and data points are very close together on the chart at day 40.

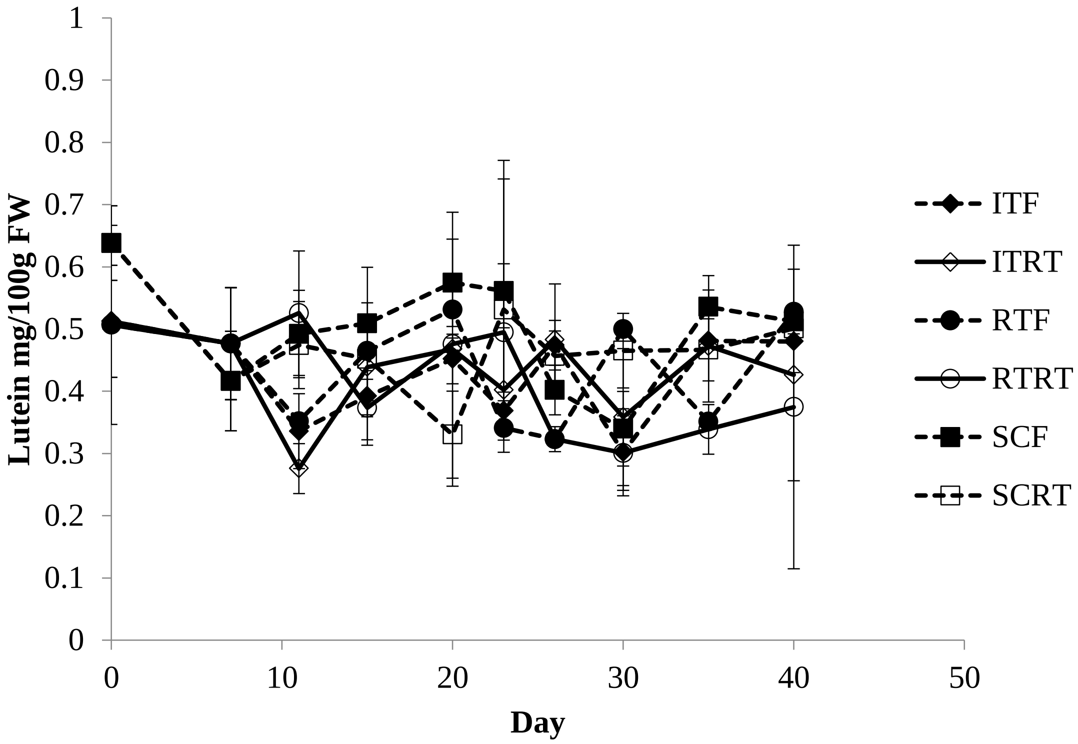

Figure 59 Mean Lutein Content of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standar error.

The repeated measures GLM output showed that only pre-sale treatment had a significant effect on lutein content for the data between day 11 and 40 ($p=0.042$), which is in contrast to the other carotenoids where no effect of pre-sale treatment was found. A statistically significant interaction was also found between month and pre-sale treatment ($p=0.009$), although month alone as a factor was not found to be statistically significant ($p=0.724$).

Post-sale treatment was found to have a significant effect on all-trans lycopene, 9-cis lycopene and β-carotene levels in tomatoes, while pre-sale was not. Day was also found to have a significant effect on these carotenoids, and this was most likely as there was an increase in dry matter which increases with ripening and weight loss. To further demonstrate this the contents of all-trans lycopene, 9-cis lycopene and β-carotene from day 11 onwards were calculated by subtracting the weight loss calculated at each time point to show carotenoid contents for dry weight (Figure 60). It can be seen that tomatoes that were exposed to post-sale RT storage had significantly higher levels of all-trans lycopene, while having generally lower accumulation of β-carotene (Table 19). In general tomatoes from RT post-sale treatment also had significantly higher 9-cis lycopene levels, although this was not apparent at day 23 and 35. Even after removing the effect of dry weight, day was still found to have a significant effect on all-trans lycopene, 9-cis lycopene and β-carotene accumulation (Table 19), suggesting that levels were increasing with time.

Table 19 Probability for All-trans Lycopene, 9-cis Lycopene and β-carotene After Removing the Effect of Dry Weight (DW). Fruits were stored at either F (5˚C) or RT (23˚C) during post-sale storage.

	All-trans Lycopene mg/100g DW	9-cis Lycopene mg/100g DW	β-carotene mg/100g DW
Source of Variation		**Probability**	
Month	0.794	0.596	0.288
Day	<0.001	<0.001	<0.001
Treatment	<0.001	0.019	0.022
Month x Day	0.002	0.049	0.041
Month x Treatment	0.320	0.349	0.438
Day x Treatment	0.544	0.160	0.010

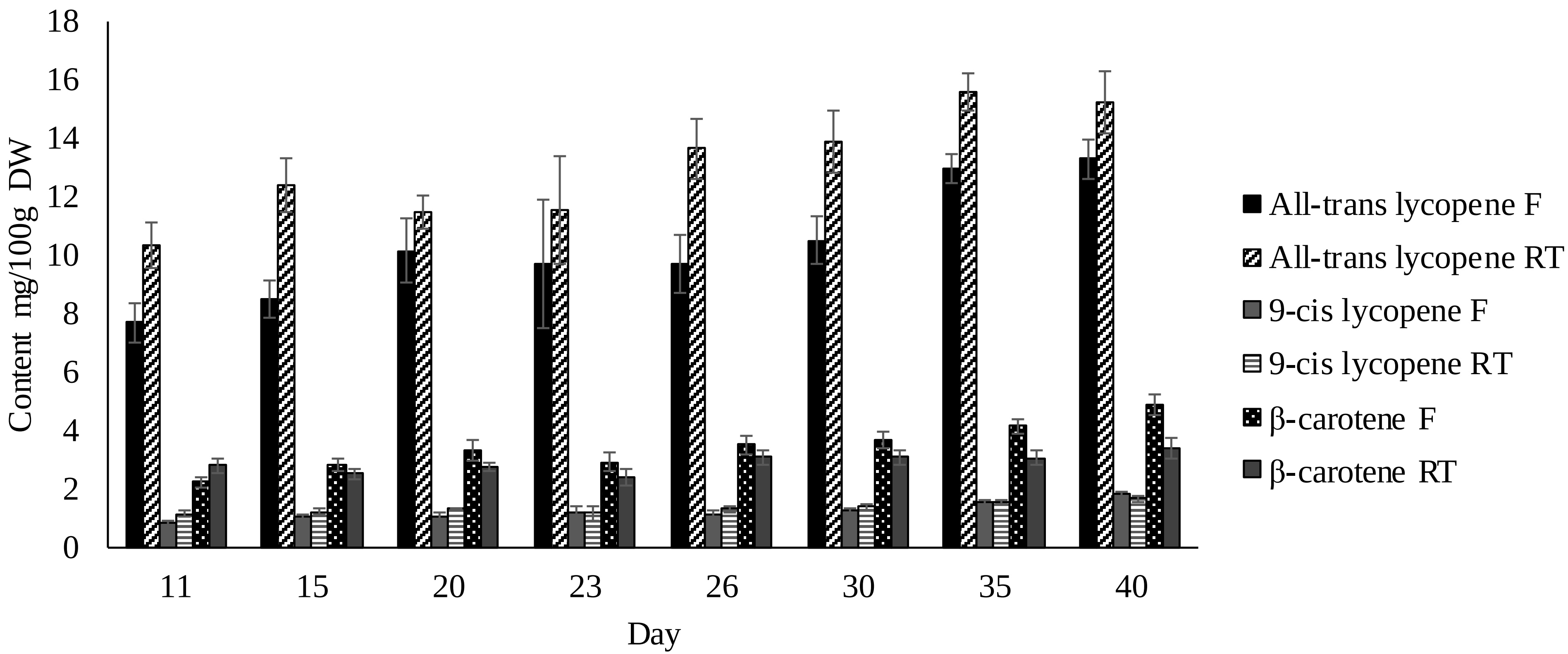

Figure 60 Mean All-trans Lycopene, 9-cis lycopene and β-carotene of Tomatoes from Post-Sale RT or F treatments after Removing the Effect of Dry Weight. Fruits were stored for 7 days at RT (23˚), IT (15˚C) or SC (average 12˚); and for the remainder of the study at either F (5˚C) or RT (23˚C). Bars represent standard error.

In summary, accumulation of all-trans lycopene, 9-cis lycopene and β-carotene was highest in tomatoes from RT treatment at day 7, and lowest in tomatoes from SC treatment. IT treatment did increase levels of both all-trans and 9-cis lycopene, and β-carotene compared with SC treatment. From day 7 onwards, post-sale treatment at RT increased levels of both all-trans and 9-cis lycopene, and these were highest in tomatoes from RTRT treatment and lowest in those from SCF treatment. For all-trans lycopene ITF tomatoes had very similar levels to that of tomatoes from SCF, suggesting that IT treatment followed by post-sale F treatment reduces all trans-lycopene accumulation nearly as much as SC pre-sale treatment does. This was also the case for 9-cis lycopene accumulation, but only until day 23, and from day 23 onwards the 9-cis lycopene levels of ITF increased and became similar to those that had any form of RT treatment. Tomato properties in terms of β-carotene were increased by keeping tomatoes from SC and IT at F post-sale treatment, while post-sale treatment at RT reduced β-carotene accumulation. At day 7, lutein levels were highest in tomatoes from RT and IT treatments; however no differences were seen as the study progressed, suggesting temperature does not have a large effect on quality in terms of lutein accumulation.

6.4.6. Phenolic Compounds

The results for sum of caffeic acid derivatives, sum of flavonoids, sum of unknown compounds, and therefore sum of phenolic compounds were very similar and general trends were seen for all with none of the phenolic compounds investigated being significantly affected by temperature treatment, or any of the factors investigated. For this reason only the results for sum of total phenolic compounds will be discussed as they are a good representation of the results for all of the phenolic analysis.

At day 7 no statistical significance was seen between any of the factors investigated for sum of phenolic compounds, although at day 0 month was found to have a significant effect (Table 20)

Table 20 Probability for the Mean Sum of Total Phenolic Compound Content of Tomatoes at Day 0 and Day 7. Fruits were stored at RT (23˚C), IT (15˚C) or SC (average 12˚C). Data was analysed by GLM.

Sum of Phenolic Compounds µg/100g FW		
Day	**Source of Variation**	**Probability**
0	**Month**	0.026
	Treatment	0.227
	Month x Treatment	0.056
7	**Month**	0.688
	Treatment	0.654
	Month x Treatment	0.023

The levels of sum of phenolic compounds increased as the study progressed (Figure 61), and this may have been due to an increase in dry weight as mentioned for carotenoids. Declines in levels were also seen at day 23 and 35 for the same reasons mentioned previously for carotenoids, and a large amount of fluctuation is also seen. At day 7 sum of phenolic compounds in tomatoes from treatments IT, RT and SC had increased by 81%, 89% and 128%. For tomatoes from treatment SCF a gradual increase is seen in content from day 23. By the termination of the study tomatoes from RTRT treatment had the largest proportion of sum of phenolic compounds, by 14-24%. At this time point ≤9% variation was seen between tomatoes from all the other treatments, and only 0.1% was seen between the sum of total phenolic compounds of tomatoes from ITF and RTF.

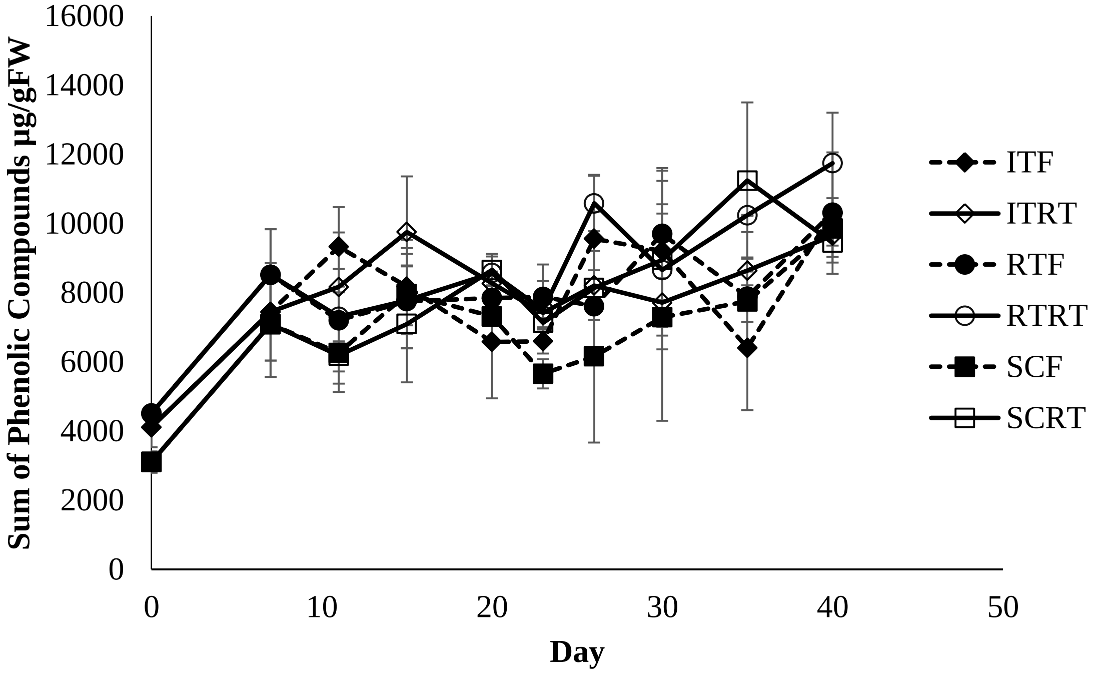

Figure 61 Mean Sum of Phenolic Compound Content of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

The repeated measures GLM output showed no statistical significance for any of the factors investigated during this study on sum of total phenolic acid content from day 11 onwards (Table 21).

Table 21 Probability for Mean Sum of Phenolic Compounds of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated measures GLM.

Source of Variation	Probability
Day	0.123
Month	0.547
Pre-sale Treatment	0.344
Post-sale Treatment	0.977
Day x Month	0.550
Day x Pre-sale Treatment	0.291
Day x Post-sale Treatment	0.526
Month x Pre-sale Treatment	0.151
Month x Post-sale Treatment	0.430
Pre-sale Treatment x Post-sale Treatment	0.144

In summary, temperature treatment did not have a significant effect on the sum of phenolic compounds. At day 7 tomatoes from RT had the highest accumulation; however, this was not significantly different from the levels found in tomatoes from IT and SC. By the end of the study tomatoes from the warmest treatment RTRT continued to have the highest levels of sum of phenolic compounds, while tomatoes from all the other treatments had similar lower accumulation.

6.4.7. Total Soluble Solids

Results were not recorded for the chemical constitutes TSS, TA, pH and Vitamin C at day 40 during May, and at day 40 for tomatoes from treatments ITF, RTF and SCF as at these time points all samples from the respective treatments had died and there were not enough samples remaining for this analysis. Chemical constitutes were not measured at day 35 in September for any of the treatments due to the researcher being unwell.

The TSS levels increased over time (Figure 62). At day 7 tomatoes from RT treatment had the highest TSS values, and SC tomatoes had the lowest, while those from IT treatment had values which were in-between the two, and treatment was found to be a significant factor at day 7 ($p<0.001$).

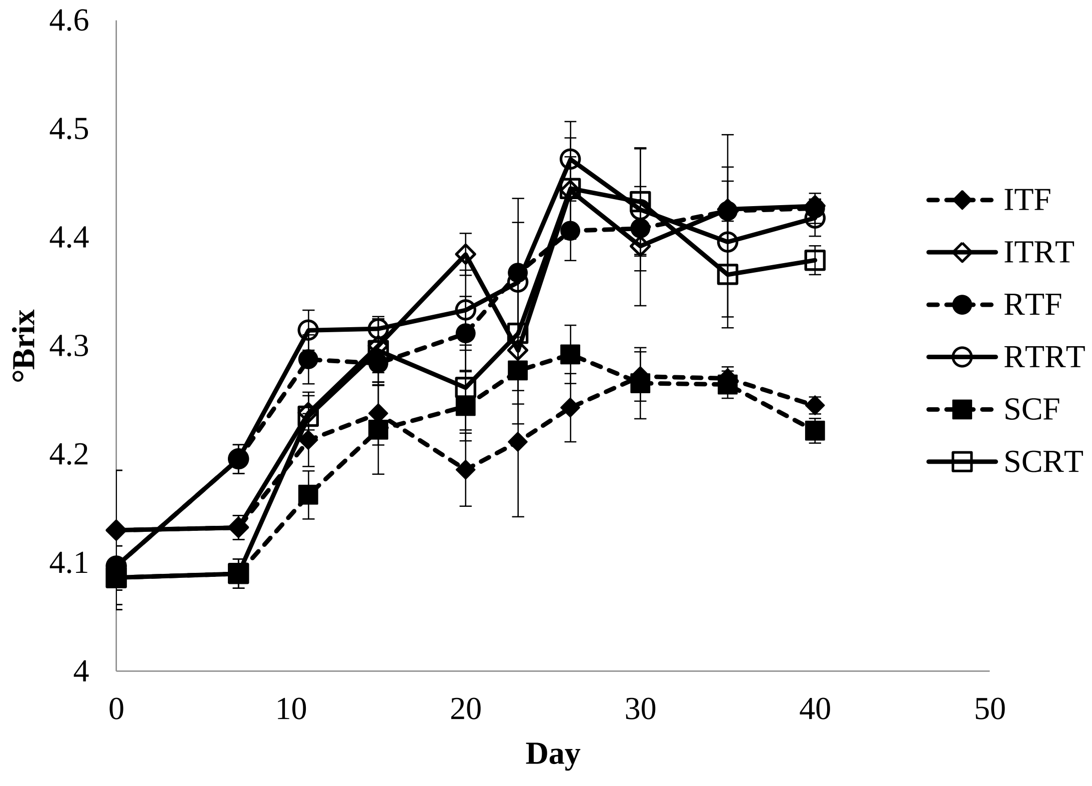

Figure 62 Mean Total Soluble Solids (TSS) (°Brix) of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

Month was found to have a significant effect on TSS values at both day 0 and 7, and tomatoes harvested in September had lower TSS values than those harvested in May and July (both $p<0.001$) (Table 22).

Table 22 Mean Total Soluble Solid Contents (TSS) of Tomatoes Harvested in May, July and September at day 0 and 7. Total soluble solids was measured as °Brix.

Day	Month	TSS °Brix
0	May	4.17 (0.05)
	July	4.17 (0.06)
	September	3.99 (0.04)
7	May	4.19 (0.01)
	July	4.14 (0.01)
	September	4.10 (0.02)

In general, from day 11 onwards tomatoes that had any form of RT storage had higher levels of TSS, however, neither pre-sale ($p=0.054$) nor post-sale ($p=0.339$) treatment was found to have a significant effect, although the GLM data did show an interaction between pre-sale and post-sale storage ($p<0.001$). ITF and SCF tomatoes had consistently lower TSS values, and this is most apparent when comparing levels between days 26 and 40 where large differences between ITF and SCF treatments and all the other treatments can be seen. For SCF tomatoes, levels increased from day 0 to day 26, but began to decline between day 26 and 40. As was seen at day 0 and 7, month was found to have a significant effect on TSS ($p<0.001$), with tomatoes from September still being lower in general levels of TSS compared with those harvested in May and July.

In summary, quality in terms of TSS contents was highest at day 7 in tomatoes from RT treatment, and lowest in those from SC treatment, although IT treatment did improve TSS accumulation compared with SC treatment. Post-sale treatment F reduced quality and levels were lowest in those from SCF and ITF, while tomatoes from all the other treatments generally had similar TSS contents, suggesting that post-sale F reduces quality further.

6.4.8. Vitamin C

At day 7 the mean Vitamin C concentration was highest in tomatoes from RT, and levels in tomatoes from IT and SC treatments were 12% and 8% lower respectively, however, this was not found to be significantly different (p=0.500) (Figure 63). Increases in Vitamin C contents were seen for all treatments between day 0 and day 15, and all treatments decreased at day 20, and fluctuated from then onwards. The data from the repeated measures GLM showed that the pre-sale treatment did not have a significant effect on Vitamin C content (p=0.075), while post-sale treatment did (p=0.023) and this was seen with F treatment producing tomatoes that were significantly lower in Vitamin C, most noticeably between day 26 and 40. Month was found to have a significant effect on Vitamin C accumulation from day 11 onwards, and tomatoes harvested in July generally had higher levels (p<0.001).

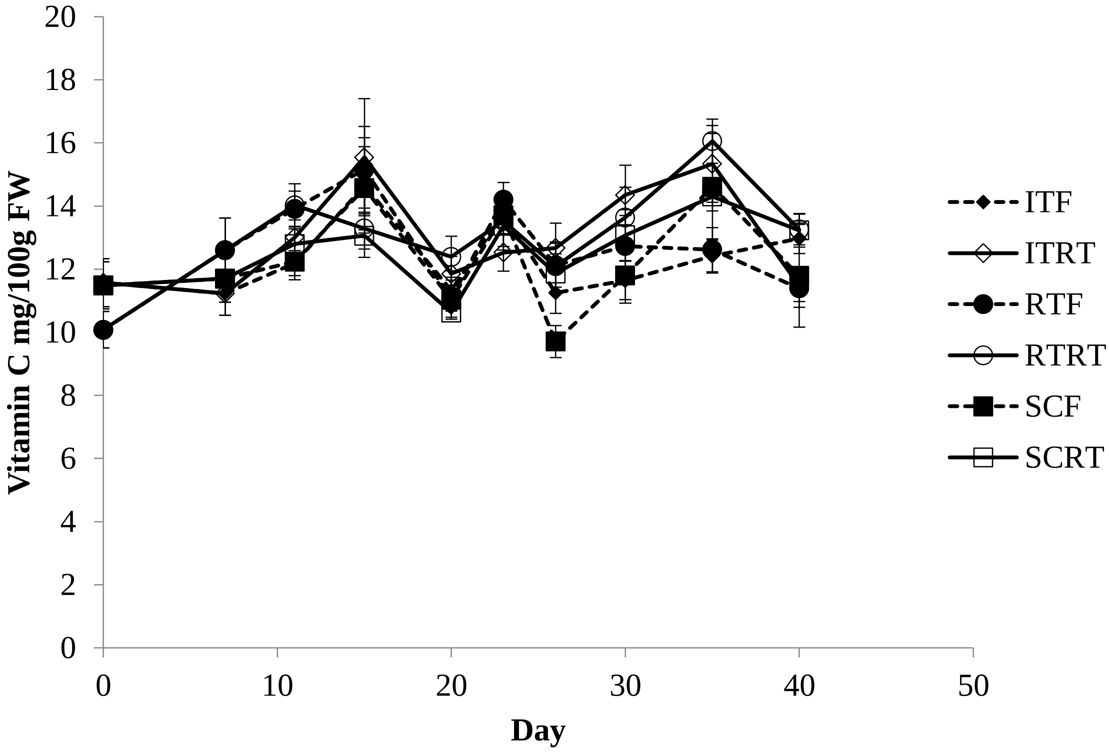

Figure 63 Mean Vitamin C Content of Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

To further demonstrate the effects of post-sale treatment on Vitamin C accumulation Figure 64 was created. There is still variation seen even when treatments are combined into post-sale treatment groups, and neither F nor RT treatment seem to consistently produce higher Vitamin C contents.

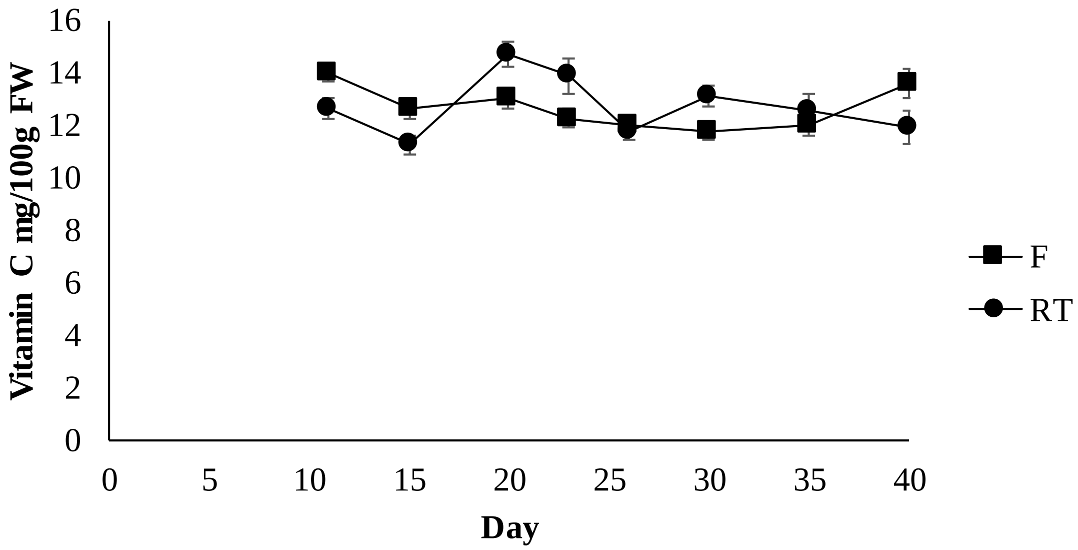

Figure 64 Mean Vitamin C Content of Tomatoes from Post-sale F (5˚C) or RT (23˚C) treatment. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either F or RT. Bars represent standard error.

In summary, quality in terms of Vitamin C contents was highest in tomatoes from RT treatment at day 7, and lowest in IT treatment, and this may have been influenced by variations within batches. In this respect, IT treatment did not improve quality compared to SC treatment

6.4.9. pH

At day 7 the GLM data showed no significant differences between treatments (p=0.312) (Figure 65) and very small variation was seen between the pH levels of tomatoes from IT, RT and SC treatments (≤1%). The pH levels were relatively stable throughout this study, although an increase in levels was seen between day 26 and 30, most noticeably for refrigerator treatments ITF, RTF and SCF (Figure 65). No effects of pre-sale or post-sale treatment or their interaction were seen for pH levels (p=0.562, p=0.091 and p=0.886 respectively).

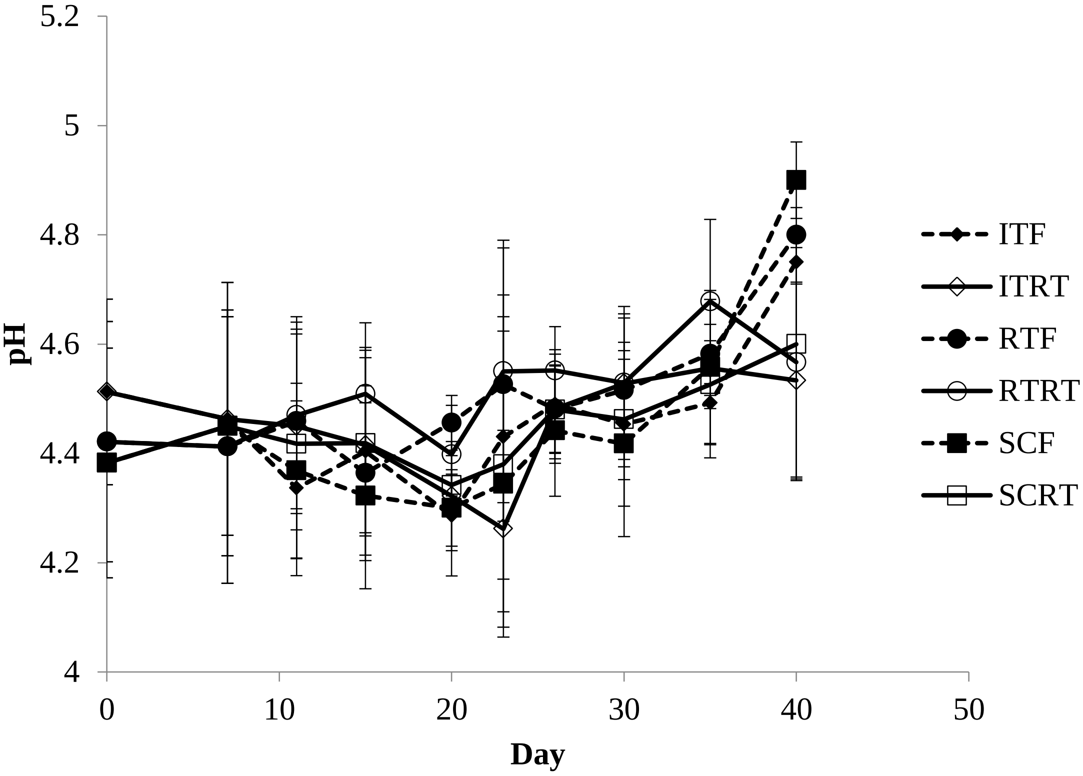

Figure 65 Mean pH for Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

For both day 0 and 7 month was found to have a significant effect on pH values ($p=0.007$ and $p<0.001$ respectively), and it appears that tomatoes harvested in May had the lowest pH values out of the study (Table 23).

Table 23 Mean pH Levels of Tomatoes at day 0 and 7. Fruits were harvested in May, July and September.

Day	Month	pH
0	May	4.27 (0.09)
	July	4.75 (0.08)
	September	4.47 (0.23)
7	May	4.16 (0.02)
	July	4.37 (0.12)
	September	4.86 (0.14)

In summary, tomato quality in terms of pH was unaffected by temperature treatment throughout this study.

6.4.10. Titratable Acidity

By day 7 17% and 18% lower levels of TA were found in tomatoes from IT and RT treatments respectively compared with those from SC treatment (Figure 66), although this was not found to be significantly different (p=0.218).

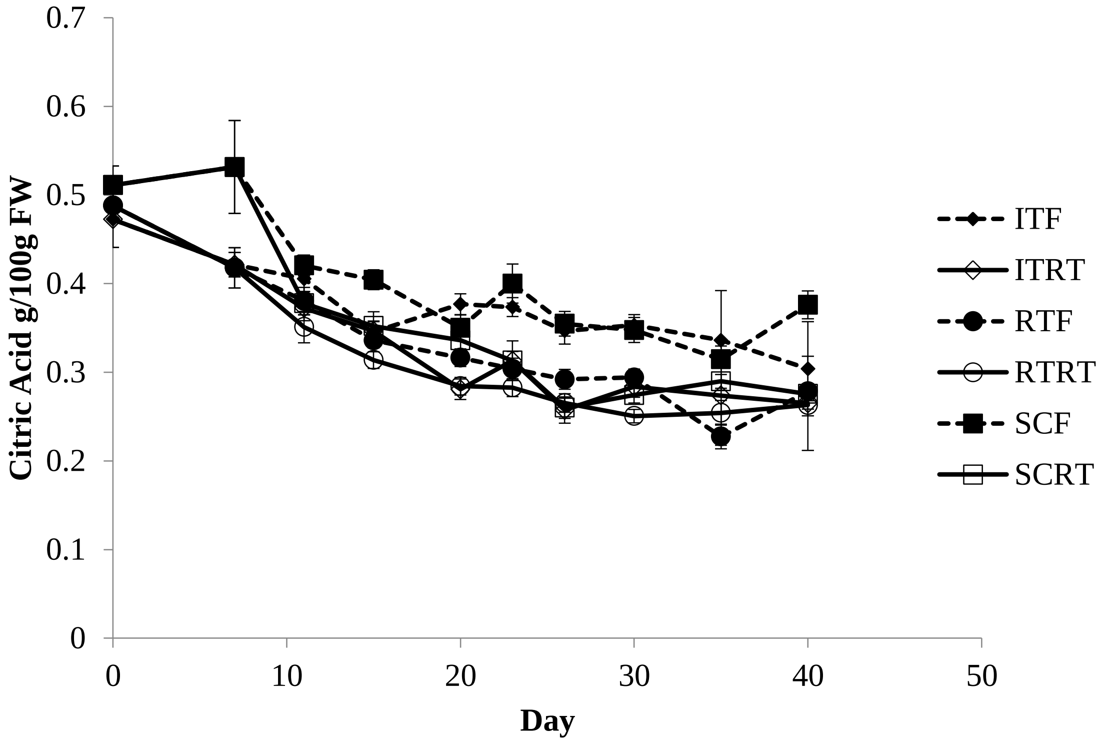

Figure 66 Mean Citric Acid Content for Tomatoes. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

Similar to the results of TSS and pH, month was found from the GLM output to have a significant effect on citric acid levels at both day 0 and 7 ($p=0.014$ and $p<0.001$ respectively), and tomatoes harvested in July had the lowest levels compared with those with earlier and later harvest dates (Table 24).

Table 24 Mean Citric Acid Contents of Tomatoes at Day 0 and 7. Fruits were harvested in May, July and September. Numbers in brackets represent standard error.

Day	Month	Citric Acid (g/100g FW)
0	**May**	0.51 (0.01)
	July	0.43 (0.03)
	September	0.52 (0.04)
7	**May**	0.55 (0.01)
	July	0.34 (0.01)
	September	0.48 (0.02)

A decrease in citric acid levels from day 11 to day 40 is seen for all treatments (Figure 66), and day was found to have a significant effect on tomato acidity ($p<0.001$). Month was also found to have a significant effect on citric acid levels ($p<0.001$) with tomatoes harvested in July having lower contents, and those produced in May having significantly higher contents. Pre-sale storage ($p=0.005$), and post-sale ($p<0.001$) were both found to have a significant effect on tomato acidity.

The repeated measures GLM data showed no interaction between month and pre-sale treatment of the citric acid levels from day 11 onwards ($p=0.472$). However, and interaction was seen between month and post-sale storage ($p=0.001$) with tomatoes that were harvested in May and then kept at F treatment having lower levels of citric acid compared to the other tomatoes. An interaction was also seen between pre-sale treatment and post-sale treatment ($p<0.001$).

To further investigate this significant effect of post-sale treatment on citric acid contents Figure 67 was created. It can be seen in general that tomatoes that were exposed to subsequent post-sale F treatment had generally higher citric acid accumulation than those from post-sale RT treatment, most noticeably for the first 15 days and between day 30 and 40.

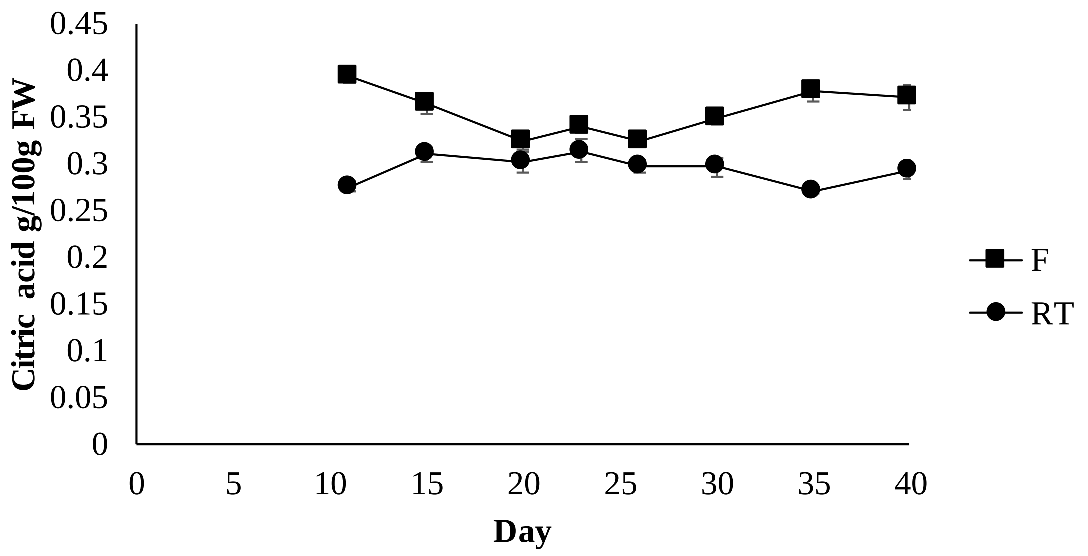

Figure 67 Mean Citric Acid Content of Tomatoes from Post-sale F (5˚C) or RT (23˚C) Treatment. Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either F or RT. Bars represent standard error.

In summary, citric acid contents were highest in tomatoes from SC treatment at day 7, while IT and RT tomatoes had similar levels, suggesting that IT treatment improves quality compared with SC as IT tomatoes were less acidic. Post-sale F treatment increased the citric acid contents of tomatoes from SC and IT treatments, and ITF and SCF had the highest levels of citric acid from day 7 onwards, while the tomatoes from all the other treatments were similar, suggesting that post-sale F treatment further increases the citric acid accumulation seen after 7 days on pre-sale storage at IT or SC, giving tomatoes of lower quality.

6.4.11. Shelf life

As expected tomato survival rate decreased over time, and this was seen in tomatoes from all treatments (Figure 68), most considerably from day 15 onwards. Between day 20 and 25 the percentage of surviving tomatoes in treatment RTF remained relatively stable in comparison to all the other treatments. However, rapid declines in surviving tomatoes were seen between day 25-27 for this treatment, as was for treatments ITF, ITRT and SCF between days 27-34. From day 34 onwards a large decrease was seen in all treatments. The overall rate of decreasing tomato survival was delayed between days 38-56 in treatment SCRT compared to the other treatments. By day 66 the percentage of surviving tomatoes had reached 0% in treatments ITF, ITRT, RTF and SCF, while treatments RTRT and SCRT did not reach total death until day 70. The average shelf life for tomatoes from each treatment was 53 days for SCF; 54 days for ITF and RTF; 57 days for ITRT; 60 days for SCRT and 61 days for RTRT.

Tomatoes from SCRT differed significantly from all the other treatments in terms of the survival calculation (all p=0.001), while tomatoes from ITRT and RTRT did not differ from each other (p=0.900) and interestingly RTF and RTRT, which had the same pre-sale treatment, were not found to differ in the outcome from the survival calculation (p=0.100), whereas ITRT and ITF were (p=0.001). Among the treatments that were exposed to post-sale F treatment, ITF and RTF were not found to have statistically different survival rates (p=0.050), while tomatoes from SCF were significantly different from both ITF and RTF treatments (p=0.025 and p=0.001 respectively).

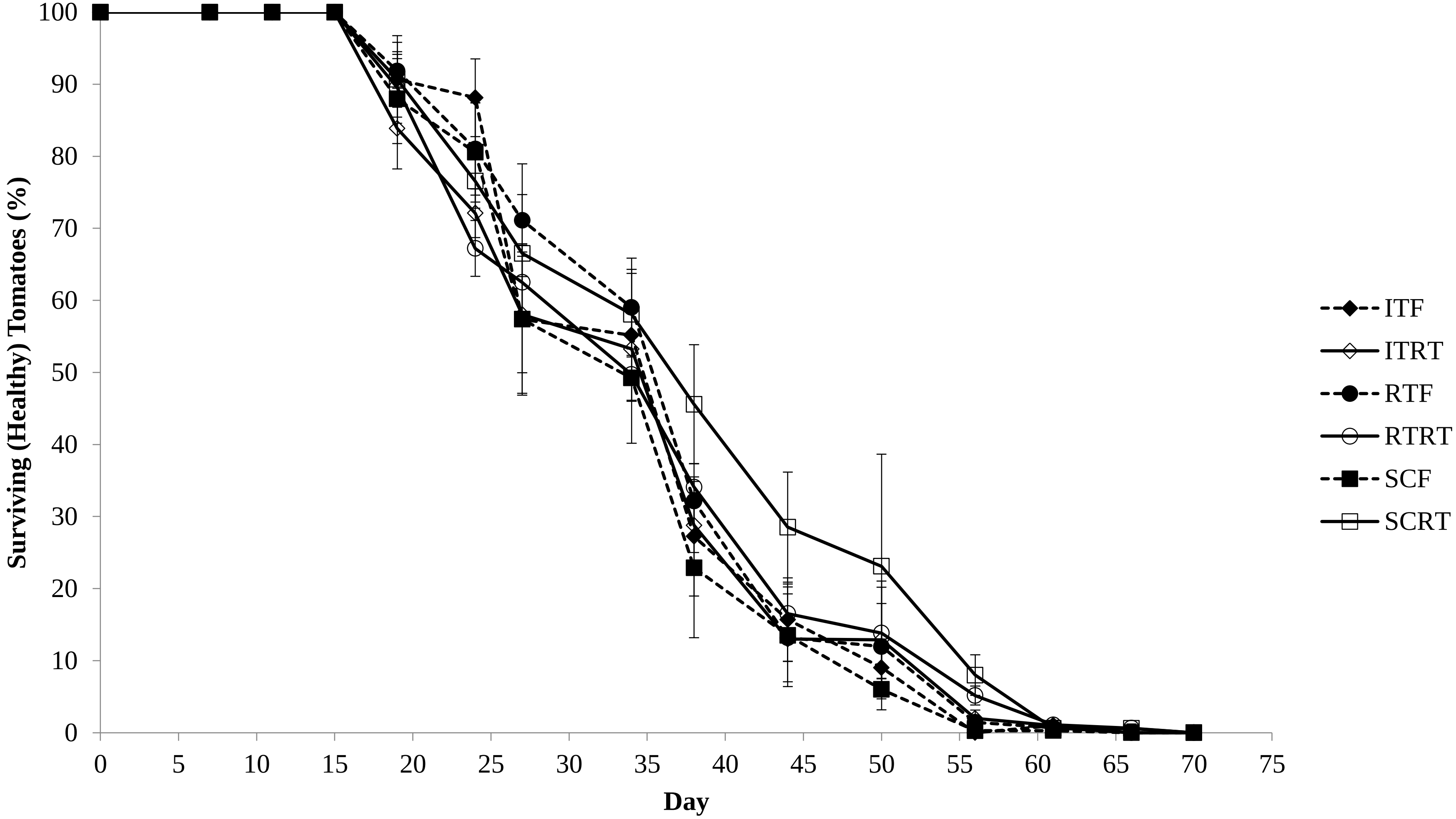

Figure 68 Number of Surviving (Healthy) Tomatoes (%). Fruits were stored at either for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Bars represent standard error.

Highest number of total decayed tomatoes was seen at the end of the study in treatments SCF, followed by RTF and then ITF (Figure 69), and these treatments had a greater percentage of total decay compared to their warmer counterpart treatments SCRT, RTRT and ITRT by 51%, 53% and 21% respectively. Post-sale treatment was found to have a significant effect on the numbers of total decayed tomatoes ($p<0.001$), whereas pre–sale treatment did not ($p=0.103$), although an interaction was found between month and pre-sale treatment, as well as month and post-sale treatment ($p=0.003$ and $p<0.001$ respectively). During this study the majority of tomatoes were harvested by the grower with their calyx still attached and the calyx was left present throughout the study, and this may have affected the numbers of decayed tomatoes as the calyx area is highly susceptible to infection (Ilic and Fallik, 2006).

For the number of wrinkly tomatoes by the end of the study the inverse was seen, and treatments ITRT, RTRT and SCRT were over 7-fold, 3-fold and 25-fold greater in percentage of wrinkly tomatoes than ITF, RTF and SCF treatments respectively, and may have also been an effect of vapour pressure deficit for the reasons explained previously in Chapter 5 (Paull, 1999). Percentage of wrinkly tomatoes in treatments that were exposed to post-sale F storage was minimal in comparison, most noticeably in SCF treatment. The percentage of tomatoes that expressed both decay and wrinkling were highest in tomatoes from ITRT and RTRT, and this was by 27-fold and 7-fold higher compared with the colder counterparts ITF and RTF respectively. For tomatoes from treatment SCF, no incidence of decay and wrinkling was observed, while SCRT treatment was lower in number of tomatoes suffering from both decay and wrinkling compared to ITRT and RTRT tomatoes. Post-sale treatment and month were found to have a significant effect on the percentage of wrinkly tomatoes (both $p<0.001$), and wrinkly and decayed tomatoes ($p<0.001$ and $p=0.031$ respectively) and an interaction was found between them for both types of shelf life ($p<0.001$ for wrinkly tomatoes and $p=0.007$ for wrinkly and decayed tomatoes).

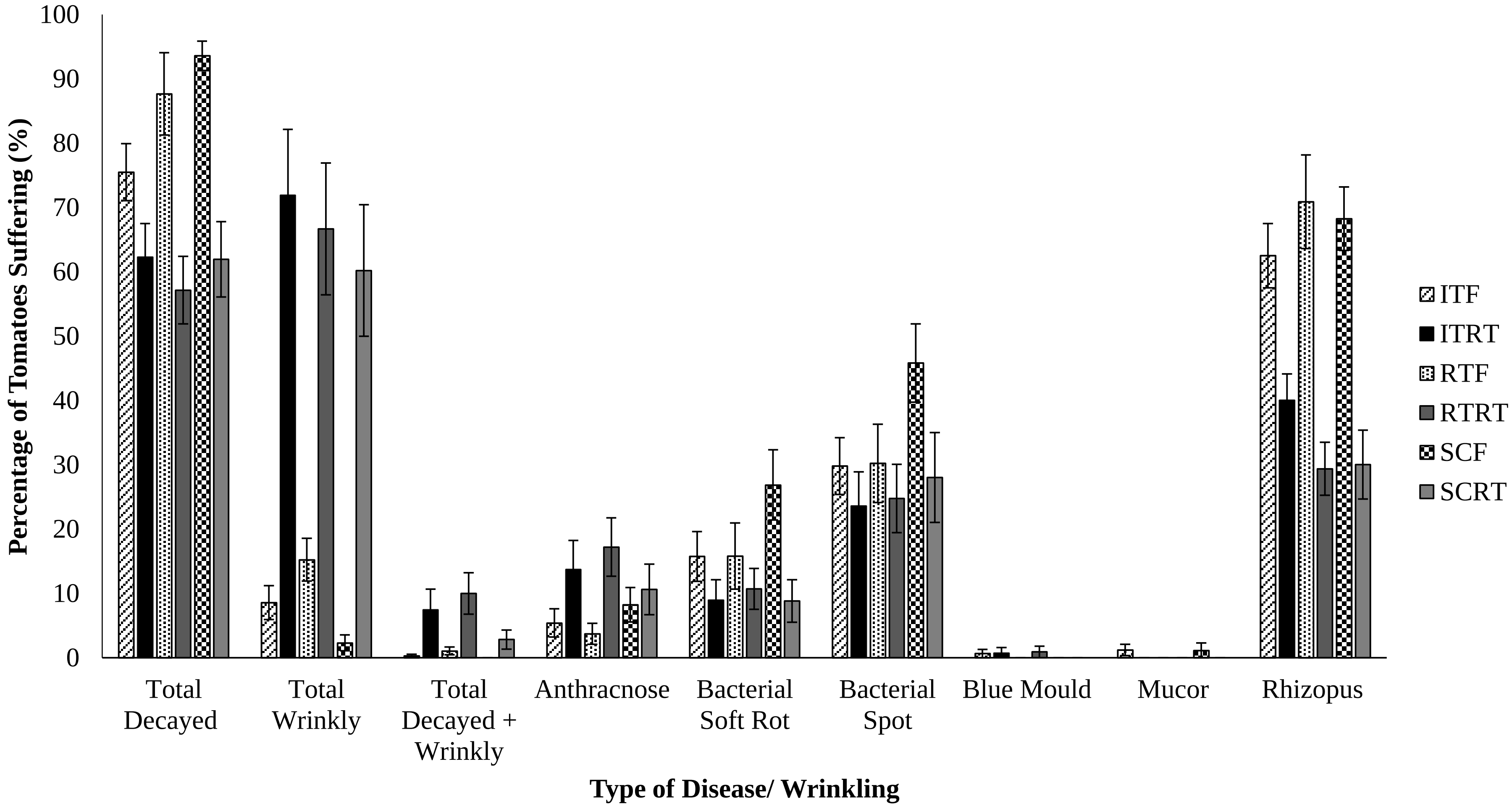

Figure 69 Percentage of Tomatoes Suffering from Wrinkling or Type of Disease by the End of the Study. Fruits were stored either for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Total decay and wrinkly indicates when a tomato is suffering from both conditions. Percentage of tomatoes for anthracnose, bacterial soft rot, bacterial spot, blue mould, mucor and rhizpous is the number of occurrences of the particular disease, therefore tomatoes that were suffering from from more than one type of disease will contribute to the percentage of each disease.. Bars represent standar error.

The percentage of tomatoes suffering from anthracnose by the end of the study was highest in treatment RTRT and ITRT respectively and lowest in ITF and RTF (Figure 69). In fact, tomatoes from ITRT and RTRT treatments had more than one and a half times, and three and half times more tomatoes suffering from anthracnose than ITF and RTF treatments respectively, while in comparison tomatoes from SCRT had only 29% more tomatoes with anthracnose than those from SCF treatment. Post-sale treatment was found to have a significant effect on numbers of tomatoes developing anthracnose ($p=0.005$). Month was also found to have a significant effect ($p<0.001$), and the percentage of tomatoes with anthracnose decay was higher in tomatoes harvested in September, showing that variation is seen throughout the tomato season.

Occurrence of bacterial soft rot was higher in tomatoes that received post-sale treatment at F, most noticeably SCF, while ITRT, RTRT and SCRT treatments had generally similar levels by the end of the study (Figure 69). Treatments ITF, RTF and SCF produced tomatoes that had 26%, 22% and 64% greater levels of bacterial soft rot than treatments ITRT, RTRT and SCRT. Post-sale treatment was found to have a significant effect on the percentage of tomatoes with bacterial soft rot ($p=0.042$) and an interaction was found between month and post-sale treatment ($p<0.001$), as well as an interaction between month and pre-sale treatment ($p=0.040$). Tomatoes harvested in May generally had lower incidences of bacterial soft rot and month was found to have a significant effect ($p=0.042$).

Blue mould was only found to occur in treatments ITF, ITRT and RTRT, and this was at very low amounts (Figure 69). No significant differences were found for any of the factors investigated during GLM analysis. Similarly, mucor mould was only seen in treatments ITF and SCF also in very low amounts. Month was found to have a significant effect on the percentage of tomatoes with mucor ($p<0.001$), and July was the only harvest month that produced tomatoes with mucor occurrence.

By the end of the study rhizopus rot was highest in tomatoes from SCF, RTF and ITF treatments, and this was by 127%, 141% and 56% than tomatoes from SCRT, RTRT and ITRT respectively. Tomatoes from RTRT and SCRT treatments had very similar percentage of rhizopus rot by the end of the study, while levels in tomatoes from ITRT were slightly higher, suggesting that post-sale RT storage reduced rhizopus rot infection regardless of the pre-sale storage phase. Post-sale treatment was found to have a significant effect on the percentage of rhizopus ($p<0.001$), and an interaction was found between month and post-sale treatment ($p<0.001$).

Since post-sale treatment was found to have a significant effect on all the types of decay seen during this study (except for blue mould and mucor), Figure 70 was created to better show the trends of the data. It can be seen that tomatoes from post-sale F treatment had higher levels of total decay, bacterial soft rot and rhizopus rot, while those from post-sale RT treatment were higher in numbers of wrinkly tomatoes, numbers of wrinkly and decayed tomatoes and those suffering from anthracnose, and was most likely influenced by the greater vapour pressure deficit seen in RT treatment compared to the other treatments.

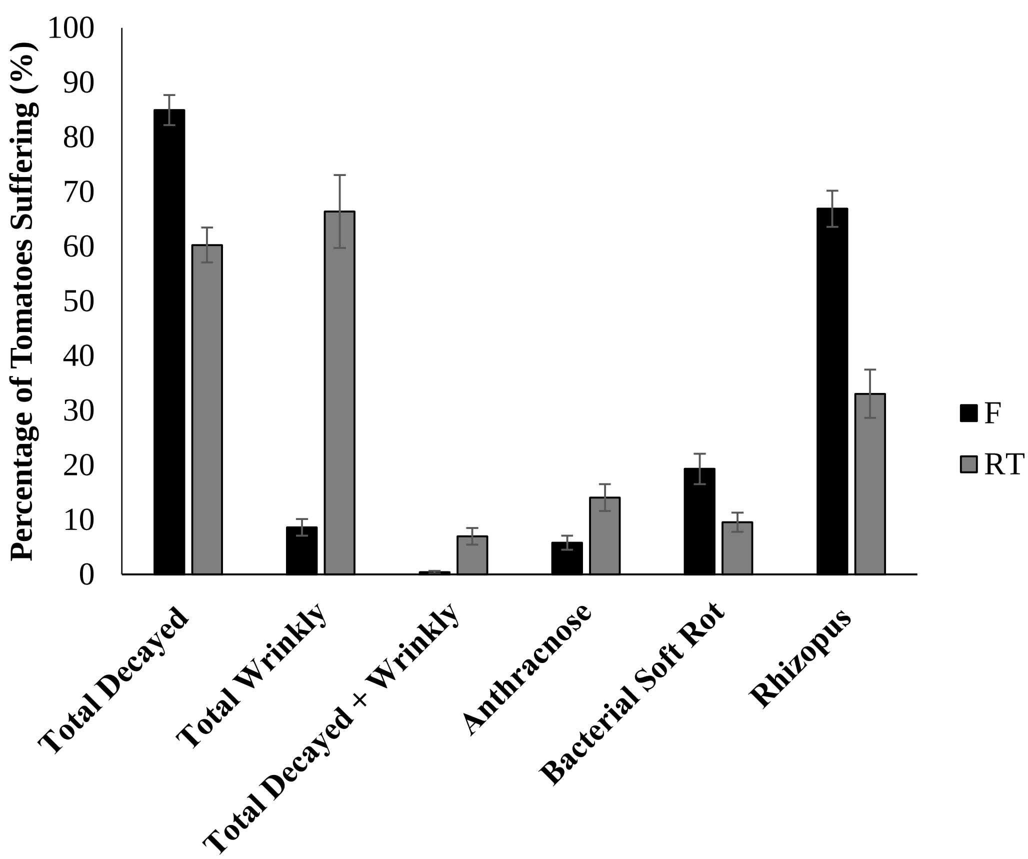

Figure 70 Mean Wrinkling or Type of Disease by the End of the Study for Tomatoes from Post-sale Treatments RT (23˚C) and F (5˚C). Fruits were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for the remainder of the study at either F or RT. Bars represent standard error.

In summary, pre-sale IT treatment did slightly improve shelf life compared to SC treatment when tomatoes from these treatments received subsequent post-sale F treatment, and tomatoes from ITF treatment had a shelf life that was one day longer than tomatoes from SCF treatment. However, tomatoes from ITRT had a shorter mean shelf life than tomatoes from SCRT by three days, suggesting that IT pre-sale treatment does not benefit shelf life if tomatoes receive post-sale RT storage, and this was most likely due to the large amount of variation seen within and between batches. Additionally, IT pre-sale treatment reduced the levels of total decay compared to SC after post-sale F treatment, and levels of total decay were highest in tomatoes from SCF and lowest in those from ITF treatment. IT treatment, however, did not reduce levels of wrinkling, and ITRT treatment had the highest levels of wrinkly tomatoes and SCF treatment had the lowest.

6.5. Discussion

In general at day 7 IT tomatoes received sensory scores from participants which lay in-between the higher scores for RT tomatoes and the lower scores for SC tomatoes. It was interesting to find that tomatoes from IT and SC treatments received similar scores for the sensory categories firmness and crunchiness, suggesting that although IT treatment did not improve overall consumer preference compared with RT at day 7, IT treatment did improve the sensorial firmness and crunchiness as scored by the participants, due to the reduced vapour pressure deficit (Paull, 1999).

After 15 days tomato sensory scores were very similar to those recorded at day 11, and not much further change was observed. Throughout this research project a reoccurring trend can be seen with tomatoes kept at the coldest treatments (either SC or SCF) always being scored the lowest in overall opinion, and also all the other categories, except firmness, crunchiness and on occasions acidity, reconfirming that the coldest treatments produce the least tasty tomatoes. Interestingly, in this study the overall opinion scores for all treatments, except SCF, were very similar and had four percent or less difference between them, supporting the concept that refrigerator storage can exacerbate the deterioration of taste already apparent from 7 day SC storage, and reiterating the importance of keeping tomatoes out of the refrigerator, as was concluded in Chapter 5.

ITF and SCF tomatoes had very similar sensory scores for firmness at day 11 and 15; however, the overall sensory opinion of tomatoes from ITF treatment was higher than the scores of the tomatoes from SCF treatment. Compared with tomatoes that had any form of RT storage (ITRT, RTF, RTRT and SCRT), ITF tomatoes had lower scores for colour, ripeness, moistness, aroma, sweetness and flavour, and higher scores in crunchiness and firmness, suggesting that generally post-sale F treatment reduces IT tomato sensorial quality, except for crunchiness and firmness. However, the sensory scores for overall opinion at day 15 for tomatoes from ITF were level with those from ITRT, RTF, RTRT and SCRT. It can therefore be concluded that post-sale F treatment did not reduce overall IT tomato preference, although did reduce the sensorial scores for all the other sensory categories, except firmness and crunchiness, which were improved by ITF storage.

Since both pre-sale treatment and post-sale treatment were found to have a significant effect on all sensory categories, this highlights the importance of improving storage as soon as the fruit has been picked until it is consumed, and suggests that both pre-sale by the producer/supplier, and post-sale storage by the consumer are crucial to tomato preference.

As was seen for the study in Chapter 5, the coldest treatment SC reduced a* values but produced higher L and b* value, therefore reducing colour development, suggesting reduced ripening. This was seen at day 7, and exposure to subsequent refrigerator storage (ITF, RTF and SCF) also produced tomatoes with higher L value than tomatoes that were kept at RT (ITRT, RTRT and SCRT). After 11 days, neither pre-sale nor post-sale treatment were found to have a significant effect on a* values, and these were only significantly affected by day, suggesting that time is more important than temperature treatment for the red development during this study, since tomatoes will continue to turn red even at chilling temperatures, although this rate will be slowed (Kader, 1986; Biswas *et al.*, 2012).

IT treatment reduced colour development at day 7 producing tomatoes with higher L and b* values compared with RT treatment. However, IT treatment had higher a* values compared to tomatoes from RT treatment, suggesting that IT treatment allowed the red colour to develop. However, these tomatoes would not have been perceived by the human eye as being as red in characteristic tomato colour as those from RT treatment at day 7, as tomatoes from IT treatment had a higher b* value, suggesting higher yellow colouration. It can therefore be concluded that IT treatment increases colour development at day 7 compared with SC treatment, but not to the extent that storage at RT treatment does.

By day 15 tomatoes from ITF treatment had higher L and b* values than tomatoes from RTF treatment, although these were not as high as tomatoes from SCF. This suggests that IT treatment followed by post-sale treatment F continues to reduce colour development that was seen after 7 days of IT treatment. However, tomatoes from ITRT treatment had similar results to tomatoes from RTRT and SCRT treatments for all colour values by day

15, suggesting that IT pre-sale treatment followed by RT post-sale treatment does not reduce colour development.

As was seen in Chapter 5, at all sample points tomatoes from the warmest treatment had the greatest weight loss (RT or ITRT, RTRT and SCRT), therefore showing that lower temperatures delay the ripening process. Javanmardi and Kubota., (2006) also found tomatoes kept at 25-27˚C had greater weight loss than those kept at 12˚C for 7 days by more than 30%, suggesting that weight loss increases in tomatoes as storage time and temperature increases. Additionally, greater weight loss seen in warmer treatments will have been caused by higher vapour pressure deficit present (Paull, 1999) as RT treatment had a much lower relative humidity than the other treatments (49.1% for RT versus 97.3%, 85.5%, and 82.3% for F, IT and SC treatments respectively). Pre-sale and post-sale treatment and their interaction were all found to be statistically significant factors on tomato weight loss, suggesting that no stage of storage is more important than the other for reducing tomato weight loss

IT treatment did reduce tomato weight loss compared with RT treatment, but not as much as SC treatment did. Post-sale storage of IT tomatoes at RT treatment increased tomato weight loss, but not to the extent that tomatoes from RTRT and SCRT were losing weight and results for RTRT and SCRT treatments were very similar, with tomatoes from ITRT being slightly lower. Furthermore, the weight loss of tomatoes from RTF and ITF treatments were similar, especially between day 23 and 40, while tomatoes from SCF had the lowest weight loss, suggesting that post-sale storage at either RT or F treatment reduces the benefits of IT treatment originally seen at day 7.

Firmness values decreased over time in tomatoes from all treatments. Both pre-sale and post-sale were found to have a significant effect on the deformation of tomatoes during this study, suggesting that temperature management at both stages are important to maintain tomato firmness, although only post-sale storage was found to have a significant effect on tomato penetration. However, an interaction between pre and post-sale were seen for both deformation and penetration.

IT treatment improved firmness in terms of deformation and penetration compared with RT treatment, although tomatoes from this treatment did not have such high deformation values as those from SC treatment, while the penetration values for tomatoes from IT and SC treatment were very similar. This further suggests that IT treatment improves firmness compared with RT treatment. However, after post-sale treatment, tomatoes from SCF were always the most firm and had the highest deformation and penetration values. Although, the deformation values for tomatoes from ITF were still high, they were not as high as those of tomatoes from SCF, while values for ITRT, SCRT, RTRT and RTF were grouped much lower, suggesting that post-sale F treatment continues to benefit tomato firmness in fruits that were exposed to pre-sale IT treatment, but not to the extent of tomatoes from SCF.

Results for tomatoes penetration did not respond the same way that deformation did to post-sale temperature treatments, and penetration values in tomatoes from ITF treatment were similar to that of tomatoes from RTF, and after 26 days tomatoes from these treatments had the lowest penetration values. It was noticed in this study that even though tomatoes from warmer temperatures felt softer and the tomatoes were easily squashed by hand, their skin is still relatively tough, and therefore it took some time for the probe to penetrate the fruit. This may be why tomatoes ITRT, RTRT and SCRT did not have the lowest penetration values by the end of the study, but did have low deformation values.

Post-sale RT treatment generally reduced the benefits seen from IT pre-sale treatment on tomato firmness and tomatoes from ITRT, RTRT and SCRT all had similar deformation and penetration values. It can therefore be concluded that 7 days IT treatment improves tomato firmness as it retains turgor compared with RT treatment, however, only post-sale F treatment maintains the firmness improvement, but only in terms of deformation.

Post-sale treatment had a significant effect on all-trans lycopene, 9-cis lycopene and β-carotene suggesting that consumer phase storage has the greatest impact on these carotenoids. Lutein, conversely, was not found to be significantly affected by post-sale treatment, but was by pre-sale treatment. IT treatment did improve carotenoids accumulation in terms of β-carotene and lutein at day 7 compared to SC treatment, although this was not found to be a statistically significant effect. From day 11 onwards an increase in level of β-carotene is seen, and the largest levels of β-carotene were recorded in tomatoes from ITF, RTF, RTRT and SCF. Interestingly between day 7 and 11 the levels of β-carotene in tomatoes from ITF and SCF were relatively constant. Moreover, in general lutein levels were relatively stable and do not appear to increase or decrease in a certain direction throughout the study. Stability in lutein and β-carotene was also seen during Chapter 5.

As was seen in Chapter 5, warmer treatments were beneficial to lycopene development. At day 7 IT treatment was found to improve all-trans and 9-cis lycopene levels compared with SC treatment, however, tomatoes from RT treatment had the largest contents. This was similar to the results of Toor and Savage, (2006) who found tomatoes kept at 15°C showed increases in lycopene levels during 10 days storage, but not to the same extent of those that were kept at 25°C. By the end of the study tomatoes that had been kept at ITRT, RTRT and SCRT had larger proportions of all-trans lycopene than those from the colder counterpart treatments ITF, RTF and SCF. Moreover, tomatoes from ITRT and RTRT treatments had very similar levels of all-trans lycopene from day 26 onwards, suggesting that post-sale RT treatment can further enhance the benefits of IT treatment seen on all-trans lycopene levels at day 7. However, this was not the case for 9-cis lycopene levels, and tomatoes from RTRT generally had the highest contents throughout the study. Post-sale F treatment reduced the benefits of IT treatment over SC treatment seen at day 7 in all-trans lycopene levels and tomatoes from ITF and SCF had the lowest accumulation for the first 23 days. This was not the case for 9-cis lycopene; however, as from day 7 contents were similar in tomatoes from all treatments, except RTRT.

Increases in phenolic contents have previously been reported in fruit after being kept cold, such as in plums kept at 2˚C for up to 50 days (Zapata *et al.*, 2014), while other fruit, such as apples, have shown stable contents after cold storage at 2˚C for up to 5 months followed by up to 7 days at 20˚C (Goulas *et al.*, 2014). During this study the sum of caffeic acid derivatives, sum of flavonoids, sum of unknown phenolic compounds and therefore sum of total phenolic compound contents increased in tomatoes from all treatments as the study progressed. The largest increase was seen between day 0 and 7 for all these compounds. Phenolic levels in tomatoes do not seem to have common response to temperature changes, and this has been shown by Garcia-Alonso et al., (2009) who exposed tomato juice to 8°C, 22°C and 37°C for up to 12 months, and Toor and Savage, (2006) who exposed untreated tomatoes to 7°C, 15°C and 25°C for 12 days. Both studies found the total phenolic and flavonoid contents remained relatively constant, while Gomez et al., (2009) found that after 15 days of storage tomatoes that were kept at 6°C had lower levels of total phenols as compared with those kept at 20°C. Moreover, in Chapter 5, the sum of total phenolic levels decreased between day 7 and 11 in all treatments, and this is in contrast to the results observed in this study, although both studies showed no significant effects of pre-sale or post-sale treatment. The difference in outcome could be due to difference between tomato varieties. Moreover, a large amount of variation was seen in all phenolic compounds investigated during this study. This was probably most likely due to the number of samples being lost to the freeze drier (55% of samples), so this may be why neither pre-sale nor post-sale treatment was found to have a significant effect on any of the phenolic compounds.

In general, IT treatment did not improve phenolic compounds accumulation compared to storage at SC treatment, as at day 7 tomatoes from RT treatment had the largest contents, while tomatoes from IT and SC had similar lower contents. Treatment, however, was not found to have a significant effect on phenolic compounds accumulation at this time. From day 7 onwards tomatoes from all treatments had similar levels, except those from RTRT treatment which had generally higher levels. By the end of the study, tomatoes from all treatments had similar levels of phenolic compounds. This suggests that IT treatment does not improve phenolic compounds accumulation even after post-sale storage.

At day 7 tomatoes from RT treatment had the highest TSS values significantly, and SC tomatoes had the lowest, while those from IT treatment had values which were in-between the two, suggesting that IT temperatures did improve TSS values as compared with SC temperatures. From day 11 onwards tomatoes that had any form of RT storage had higher levels of TSS, while ITF and SCF tomatoes had consistently lower TSS values. This suggests that post-sale F treatment reduces the beneficial effects seen from IT treatment over SC treatment at day 7.

Pre-sale treatment did not have a significant effect on Vitamin C content, while post-sale treatment did, suggesting that consumer phase storage is more important in terms of Vitamin C accumulation than supermarket phase storage. This was interesting to find since it had already been documented that Vitamin C contents decrease during freezing and boiling (Waheed-Uz-Zaman and Mehwish, 2013), reconfirming the idea that Vitamin C levels at the time of tomato consumption are influenced by consumer storage/preparation.

Previously it has been found that tomatoes left to ripen on the vine at room temperature have higher levels of Vitamin C than those kept at 4°C (Nicoletto *et al.*, 2012), suggesting that warmer temperatures may increase Vitamin C levels. This was seen during this study with the mean Vitamin C concentration being highest in tomatoes from RT at day 7 and lowest in tomatoes from IT treatment although this was not significantly different from those from SC treatments. From day 7 Vitamin C levels fluctuated throughout the study, and by the end tomatoes had only increased in levels slightly. It can therefore be concluded that IT treatment did not improve Vitamin C levels compared with SC treatment

At day 7 no significant differences between treatments were seen for pH levels of tomatoes from RT, IT and SC. pH levels were relatively stable for the first 26 days in this study, although an increase in levels was seen between day 26 and 30, most notably for refrigerator treatment ITF, RTF and SCF. In chapter 5, pH values increased between day 7 and 11 in all treatments, so the differences seen within this study may be due to a different tomatoes variety being used. It can therefore be concluded that in this study temperature did not have an effect on pH levels

During this study the titratable acidity levels decreased as the storage time increased. This was also seen in tomatoes held at 13˚C for 40 days (Majidi *et al.*, 2011) At day 7 tomatoes from SC treatment had considerably higher contents of citric acid than those from IT and RT treatments, which were very similar. However this was not found to be significant. Tomatoes from SCF and ITF treatment had the highest levels of citric acid, with tomatoes from SCF treatment generally being highest, while tomatoes from all the other treatments were lower. Pre-sale treatment and post-sale treatment had significant effects on citric acid content, and an interaction was seen between pre-sale treatment and post-sale treatment, suggesting that both storage phases play an important role in citric acid levels. It can therefore be concluded that temperatures have an effect on the citric acid accumulation of the tomatoes during this study, and that levels are highest in the coldest treatment (SC or SCF), producing tomatoes that were more acidic. This has also been shown in tomatoes kept at 6˚C which had the highest TA levels compared with those kept at 9˚C and 12˚C for 21 days (Artés *et al.*, 1998). Higher levels of acidity was also reported in the sensory findings of this study for tomatoes kept cold, and is most likely due to reduced acidity observed in tomatoes kept at warmer temperature due to their higher respiratory rate (El-Anany *et al.*, 2009).

As expected tomato survival rate decreased over time, and this was seen in tomatoes from all treatments. The overall rate of death was delayed in treatments RTRT and SCRT. In comparison to survival rates seen in Chapter 5 there is not such a large difference between those that were exposed to subsequent RT and those kept at F storage, even though tomatoes from post-sale F treatment had higher pathogen susceptibility. This is since during this study visual skin defects such as wrinkles were taken into account and when tomatoes showed more than 15% skin defects they were considered ‘inedible’ and removed from the treatment. Since the percentage of wrinkly tomatoes was much higher in treatments ITRT, RTRT and SCRT than ITF, RTF and SCF, this reduced the large differences seen between the two post-sale treatments in Chapter 5.

In conclusion, IT treatment significantly improved tomato shelf life compared with SC treatment when tomatoes were exposed to post-sale F treatment. However, when IT tomatoes were exposed to post-sale RT treatment, IT temperatures were not found to be beneficial to tomato shelf compared to SCRT treatment, and tomatoes from SCRT had a significantly longer shelf life than those from ITRT.

The highest number of total decayed tomatoes was seen at the end of the study in treatments SCF, followed by RTF and then ITF, and these treatments had greater percentage of total decay compared to their warmer counterpart treatments SCRT, RTRT and ITRT. This suggests that post-sale F treatment causes the greatest levels of disease, with the coldest treatment SCF having the highest levels as was seen in Chapter 5. Moreover, the number of tomatoes suffering from rhizopus rot was higher in tomatoes that were stored in post-sale F treatment, and this was also the case for bacterial soft rot, which was most noticeably highest in SCF tomatoes. However, the percentage of tomatoes suffering from anthracnose by the end of the study was highest in treatment RTRT and ITRT respectively and lowest in ITF and RTF. This shows the influence of post-sale storage as these treatments derived from either IT or RT pre-sale treatments, and shows the anthracnose was more prevalent at warmer treatments, while at F post-sale treatment little growth of anthracnose was seen.

Only post-sale treatment was found to have a significant effect on the number of tomatoes that were decayed, wrinkly, wrinkly and decayed, suffering from anthracnose, bacterial soft rot, or rhizopus. This suggests that consumer phase storage is more important in controlling decay and mould levels. Moreover, from this it can be concluded that the coldest treatment SCF cause the greatest levels of pathogen incidence.

Tomatoes from post-sale RT treatment had the largest amount of wrinkling with tomatoes from ITRT treatment being the most affected, and those from post-sale F treatment had the lowest amounts, with tomatoes from SCF being the least wrinkly. A similar outcome was seen for the percentage of tomatoes that expressed both decay and wrinkling, while for tomatoes from treatment SCF, no incidence of decay and wrinkling was observed. It was interesting to see RTF tomatoes having much lower wrinkling than tomatoes from treatments that had post-sale RT treatment, even though they all were exposed to RT temperatures at some point. However, tomatoes from RTF did have the highest levels of wrinkling out of the tomatoes from the post-sale F treatments.

Wrinkly tomatoes were removed from the treatments and were considered at the end of their shelf life. Since the producer/consumer would remove tomatoes that were visibly wrinkly/shrivelled and these would not be consumed, this method is advantageous to the method used in Chapter 5 as it provides accurate information on the shelf life of tomatoes, rather than only providing information on the disease resistance. However, a disadvantage of this method is that it does not provide an insight into what type of pathogen the tomato may suffer from if left in the treatment. Therefore, which method is employed during a research study depends on the purpose of the study. For research that focuses on the type of fruit pathogen, the method used in Chapter 5 is more suitable, while for research that is investigating the time a producer/consumer would consider fruit at the end of the shelf life then the method used within this chapter is more apt.

The higher proportion of tomatoes from RT treatments suffering from wrinkling was most likely caused by the breakdown of fruit cell walls association with increased ripening and increased water loss through transpiration at higher temperatures (Fischer and Bennett, 1991; Hadfield and Bennett, 1998), therefore also causing weight loss. In this study F treatment had an average relative humidity of 97.3% while RT treatment had an average relative humidity of 49.1%, and since higher relative humidity reduces fruit weight loss, this may have been why tomatoes from post-sale F treatment generally did not suffer from skin wrinkling. Therefore, there are implications that increasing the relative humidity may reduce the wrinkling seen in the tomatoes from post-sale RT treatment, which would lower the vapour pressure deficit (Paul 1999). However, higher relative humidity at higher temperatures has been associated with higher pathogen incidence. This has been shown in apples where levels of *Escherichia coli* O157:H7 were most prevalent after storage at 15˚C for two days with a relative humidity of 100%, rather than 85% or 68% (Tian *et al.*, 2013), suggesting that relative humidity increases fruit pathogen growth. However, since warmer temperatures alleviate CI in tomatoes, it may not be that the susceptibility of the tomato fruit to disease is higher at higher temperature and higher relative humidity, but that the growth of tomato pathogens will be higher and disease numbers will increase rapidly. Therefore, it is most likely that higher relative humidity will not be beneficial to tomatoes when kept at RT in terms of keeping tomato infection low.

Post-sale treatment was found have to have a significant effect on tomato wrinkling, while pre-sale treatment was not, suggesting that consumer storage has the greatest effect on tomato quality in terms of skin wrinkling, compared with storage during the supply chain. It can be concluded that RT causes wrinkling in tomatoes, and this was seen both from all post-sale RT treatments having higher levels of wrinkling than tomatoes from post-sale F treatments, and also from the higher wrinkling seen for RTF tomatoes compared to ITF and SCF out of the tomatoes from post-sale F treatment.

Highest number of total decayed tomatoes seen in tomatoes from ITF, RTF and SCF treatment was most likely as a symptom of CI (Hobson, 1987; Maul *et al.*, 2000), and this was the only symptom of CI seen in this study apart from reduced flavour and aroma during sensory results (Maul *et al.*, 2000). The higher sensory scores seen in IT tomatoes compared with those from SC treatment suggest that tomatoes from IT treatment were not exposed to CI inducing temperatures. The longer shelf life seen for tomatoes from ITF treatment compared with SCF treatment, most noticeable when comparing levels of decay, are also most likely to have been since IT treatment was warm enough to prevent CI for the first 7 days. It can therefore be concluded that IT temperatures relieved the effects of CI compared to SC treatment.

Month was found to have a significant effect on sensory scores, suggesting that variation was seen throughout the tomato season for aroma, acidity, firmness and crunchiness, with tomatoes harvested in July having greater levels of aroma, and those harvested in May having lower scores in firmness and crunchiness, than tomatoes from September, but higher levels of acidity. This is presumably due the various pre-harvest factors such as light irradiance which will vary throughout the tomato season, since light exposure has been found to affect fruit quality in strawberries where fruit that were kept under 47% shade for two weeks had lower levels of volatiles and sucrose than those from 25% shade and 0% shade (Watson et al., 2002). In another study, it was found that exposure of greenhouse tomatoes to LED lamps during growth produced tomatoes that were higher in sweetness, juiciness and overall eating quality than control tomatoes (Kowalczyk *et al.*, 2012). Tomatoes harvested in July will have had the greatest amount of light exposure due to the longer days and stronger sun, so this may explain why they were scored higher in aroma levels. Additionally, according to the Met Office, tomatoes that were harvested in May in this study were exposed to 199 hours of sunshine six weeks prior to being harvested, while those harvested in July were exposed to 221 hours, and those with a harvest date in September were exposed to 141 hours, so this may explain the large amount of variation seen between harvest months (MetOffice, 2013). Variation in sensory results will also be due to participant variation between experiments, as mostly different volunteers participated each time. Nevertheless, this research produced highly significant data, and as concluded in Chapter 3, the comparative consumer profiling used in this research provided similar sensitivity as in comparable studies using trained panels (Varela and Ares, 2012; Vidal *et al.*, 2014),

Month also had a significant effect on all the half tomato colour values with tomatoes harvested in May having higher L and a* values, while those with a harvest date in July had lower L and a* values. This may be due to seasonal variation caused by pre-harvest factors as reported for the sensory results, but may also be due to harvesting techniques, as although the grower that supplied the tomatoes during this study aimed to pick at ripening stage three, some tomatoes were harvested at colour stage one or two when it was the end of the week, or if the last tomato on the truss was slow to ripen. To reduce this bias tomatoes should be harvested when they are all at the same ripening stage and ensure quality checks during sorting and packaging to ensure this is being implemented (van der Vorst *et al.*, 2014).

Tomatoes harvested in July irrespective of treatment, had greater deformation values than tomatoes harvested in May and September, except for a few occasions. These tomatoes also had the highest accumulation of Vitamin C and the lowest levels of citric acid, while tomatoes harvested in May had the lowest pH levels. Month also had a significant effect on TSS values, with tomatoes from September having lower TSS values than those harvested in May and July, suggesting that by September tomatoes may have been of lower quality. This may have been since they were harvested at the end of the tomato season within the UK.

Month also had an effect on the type of tomato death. July was the only month with tomatoes with mucor rot infection, while tomatoes harvested in September had the highest levels of anthracnose. Tomatoes harvested in May had the lowest levels of wrinkly tomatoes, decayed and wrinkly tomatoes, tomatoes with bacterial soft rot and bacterial spot. The reason tomatoes from May had the lowest levels of wrinkly and decayed and wrinkly tomatoes was most likely due to the fact that they had the highest levels of total decay out of the tomato season, therefore, more tomatoes were being lost to decay rather than left to wrinkle which generally tended to occur at a later stage during this research. However, month was not found to have a significant effect on total decay.

It can be concluded that month has an effect on tomato quality, with tomatoes harvested in September generally being of the lowest quality in terms of TSS accumulation and the number of tomatoes suffering from anthracnose, and tomatoes harvested in July generally being of the highest quality during this study with highest levels of aroma, deformation and Vitamin C, although tomatoes harvested in May generally had the lowest levels of wrinkly tomatoes and highest levels of total decay.

Conclusion

Tomatoes that were kept the coldest were always the consumers' least favoured fruit at every sensory experiment during this study, and refrigeration storage at consumer level was uniformly detrimental to sensory quality, as this was also seen in Chapter 5 even when using a tomato of a different variety, and also after packaging the tomatoes. Intermediate temperatures of 15°C did delay the onset of ripening with respect to colour development, firmness (both instrumental and sensorial) and weight loss compared with RT treatment. IT pre-sale storage also improved lycopene contents, TSS accumulation and consumer overall opinion compared with the results of SC tomatoes, however, this was not on par with those from RT treatment, which consistently produced the consumers' most preferred tomatoes at day 7 during this entire research project. After post-sale phase, SCF tomatoes were always the consumers' least favoured, while tomatoes from ITF were scored as highly as those that had any form of RT storage, suggesting that IT pre-sale treatment was also more beneficial to tomatoes at day 11 and 15 than SC treatment in terms of sensory opinion. As was seen in Chapter 5, no signs of CI were seen except for the reduced sensory scores and shelf life of tomatoes from SCF treatment, suggesting that IT treatment relieved CI compared with SC, delayed the ripening process compared to RT treatment, and ITF treatment improved shelf life compared to SCF, but SCRT treatment had a longer shelf life than ITRT.

In this study the month of harvest was commonly found to have a significant effect on various tomato qualities, especially tomatoes harvested in September which had lower levels of TSS and higher susceptibility to anthracnose rot than those harvested in May and July, and May tomatoes generally had the lowest levels of disease incidence, while tomatoes from July were generally of the highest quality, suggesting that there is variation seen throughout season (Verkerke *et al.*, 2001).

This research reinforces the importance of keeping supermarket tomatoes out of the refrigerator, with respect to consumer opinion, lycopene levels, disease incidence and levels of ripening. Although this study did show IT to generally produce more preferable tomatoes to SC, on many occasions RT tomatoes were of the highest quality. It can therefore be concluded that the optimal temperature for postharvest storage of tomatoes lies somewhere between 15°C and 23°C, and may even be above 23°C.

Overall Conclusion

It can be concluded that temperatures above those used in the supply chain, and/or room temperature during post-sale storage positively affect the sensory perception of fruit, and this was shown in round salad tomatoes, red and green grapes, and nectarines where a room temperature of 22˚C was found to give higher taste scores compared with storage at refrigerator temperatures of 6˚C. It was also shown in round salad tomatoes kept at either 15˚C or 23˚C compared with supply chain temperatures, where tomatoes that were kept the coldest were always the consumers' least favoured fruit at every sensory experiment during this study (SC or SCF). Room temperatures also produced higher levels of lycopene, and in some cases produced higher levels of phenolic compound accumulation, compared with storage at supply chain temperatures or refrigerator temperatures. This suggests that higher temperatures than those used in the supply chain during the pre-sale phase and refrigeration during the post-sale phase positively affect tomato nutritional quality in terms of lycopene and phenolic compound accumulation, therefore giving tomatoes of higher quality.

Vitamin C and titratable acidity levels were generally higher in tomato fruit that was kept cold, suggesting that supply chain temperatures or lower positively affect Vitamin C and titratable acidity levels. Total soluble solid contents were generally highest in fruits from RT treatments during both pre and post-sale storage phases, and fruit colour development, weight loss and firmness reduction were always higher in room temperature treatment at both stages, suggesting that temperatures above supply chain temperatures during the pre-sale storage phase and temperatures above refrigerator temperatures during the post-sale phase have a positive effect on these quality attributes, while pH was generally unaffected by temperature. Shelf life was reduced when tomatoes were kept cold and this, along with lower sensory scores, was most likely as a result of chilling injury (CI), suggesting that temperatures above the supply chain temperatures relieved CI and allowed for development of tomato properties associated with tomato ripening.

Future Work

This research has demonstrated the impact that storage temperatures can have on the post-harvest quality of fruit. Regarding the supply chain period, the results indicate a potential for substantial improvements in the quality of freshly harvested round salad tomatoes in the UK, affecting consumer experience in terms of sensory quality, nutritional composition and shelf life. The results emphasise the need for further research into optimisation of the temperatures used, and suggests that the optimal temperatures will lie somewhere between 15°C and 23°C, or above. Optimisation will not only improve consumer satisfaction, and nutritional value in terms of lycopene, but also directly save costs for the supermarkets by reducing the energy expenditure for cooling tomatoes.

Regarding the post-sale period, it is imperative to develop and implement new guidelines for tomato temperature management by the consumer, considering not only the sensory quality and shelf life, but also that in most climates room temperature near 23°C is more energy efficient and less costly than refrigeration. Since the greatest benefits were observed during the simulated post-sale period, a first initiative could be a concerted education campaign aiming to change consumer behaviour and keep tomatoes out of the refrigerator, just as most consumers have learnt to do with fruits such as bananas. This could be done by improving information on packaging and through various media outlets.

In terms of further research, it would be relevant to investigate the cellular reactions that are occurring within tomatoes in response to changing temperatures and provide insight into the cell mechanisms and what genes are being turned on or off at different temperatures, in tandem with research into the nutritional and sensory properties, and shelf life. This would give a better understanding of why tomato quality and disease resistance are negatively affected by low temperatures and/or vapour pressure deficit.

Finally, it must be assumed that similar misalignments of usual practice with the fruits' physiological status may also occur for a wide range of other subtropical and tropical fruits, which may benefit from warmer temperatures, such as nectarines and grapes as concluded in Chapter 2. It would therefore be relevant to reassess the supply chain temperature management for these fruit species as well, to identify more cases where the fresh produce industry can improve consumer satisfaction and in the process save energy, money and waste.

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Appendix A: Paper Work for Sensory Analysis

Consumer Evaluation of Tomatoes

What is involved?

- Volunteers will taste different tomatoes and rank them on a score card.
- Volunteers will taste 5 sets of tomato slices
- Each tomato samples will be 1/8 of a tomato
- Volunteers will receive a incentive for their time.

Consumer Evaluation of Tomatoes

Newcastle University

Nu-food

School of Agriculture, Food and Rural Development

Agriculture Building

Newcastle upon Tyne

NE1 7RU

Study Contact: Rosemary Dew

Telephone: 07515463220

Email: rosemary.dew@ncl.ac.uk

Consumer Evaluation of Tomatoes

Information Sheet for Volunteers

20/05/13

Newcastle University

Nu-food

School of Agriculture, Food and Rural Development

Agriculture Building

Newcastle upon Tyne

NE1 7RU

Study Contact: Rosemary Dew

Telephone: 07515463220

Email: rosemary.dew@ncl.ac.uk

Figure 71 Example of Information Sheet used during Sensory Analysis Page One

You are being invited to take part in a research study.

Before you start it is important you understand what it will involve. Please take time to read the following information carefully. Please ask if there is anything that is not clear or if you would like more information.

What is the purpose of this study?

The aim of this experiment is to establish whether consumers of tomatoes can taste a difference between tomatoes that have been stored in different conditions. There is no genetic modification or chemical additions being used within this research, everything is completely natural!

Do I have to take part?

It is up to you whether you take part. After reading this information sheet if you are interested in volunteering, you will first be asked to sign a consent form to ensure you are a suitable volunteer. You will be free to withdraw from the study without giving a reason at anytime. If you enjoy eating tomatoes and have no known allergies/intolerance to them then you are an ideal candidate.

What will volunteering involve?

The taste testing will take place in the NU-Food sensory facility, which contains a series of cubicles located in the basement of Newcastle University's Agriculture Building. The tasting session will take about 25 minutes. To take part in a taste test, you will enter a cubicle and close the door behind you. First you will be asked to taste 3 different tomatoes, sipping water between each sample and scoring them on a anonymous score card. When you are finished please press a button to inform the researcher that you are ready for your next portion. You will then be presented with 3 further samples, which you will be asked to rank on the score card in the same way as before. This step will be repeated 3 times. You do not need to eat all of your tomato slice. When you have finished we will give you a small incentive for your time.

What are the possible disadvantages of taking part?

There are no known disadvantages. However, if you suffer from a known tomato intolerance or allergy you will not be allowed to participate. The researcher has a Level 2 Food Handler certificate and will take great care during tomato sample preparation.

What are the possible benefits of taking part?

Although you may not derive any individual benefit, the knowledge gained from this study will help research to develop better ways to store tomatoes, so your volunteering is greatly appreciated!

What happens if I decide I want to quit during the study?

If you wish to withdraw from the study then please inform Rosemary Dew. You have the right to withdraw from the study without prejudice and without providing a reason. If you decide to leave before completing the taste testing then your data will be disregarded.

What happens if something goes wrong?

Any complaints you have about this study should be made to Dr Kirsten Brandt, Newcastle University (kirsten.brandt@ncl.ac.uk or 0191-2225852) and will be fully investigated.

Will my taking part in this study be kept confidential?

Yes. If you agreed to be contacted for further research then any information you provided will be kept strictly confidential.

What will happen to the study results?

The results will hopefully be published in a scientific journal and on the project website. You will not be personally identified in any publications. We will be happy to discuss the results with you when the study is completed, and will let you know where you can obtain a copy of any published results if you wish.

Who is organising and funding the study?

This study is being organised by Newcastle University. ASDA is funding the research.

Contact for further information

If you would like any further information about this study please do not hesitate to contact Rosemary Dew on 07515463220 or rosemary.dew@ncl.ac.uk. Finally, thank you for having taken the time to read this information sheet and for your interest in the study.

Figure 72 Example of Information Sheet used during Sensory Analysis Page Two

Consumer Evaluation of Tomatoes

Questionnaire

Please circle the appropriate selection

Age: 18-24 25-34 35-44 45-54 55-64 65+

Gender: Female Male

Do you smoke? : Y / N

Are you suffering from a cold? : Y / N

Have you eaten or drunk any foods in the last hour which may affect your ability to taste food? (e.g. Coffee/ Curry): Y / N

If you answered yes for the question above what food have you eaten?

____

Figure 73 Example of Questionnaire Used during Sensory Experiments

Test 1

Please score your samples on the line scales below labelling 'A' for sample A, 'B' for sample B and 'C' for sample C :

1) **Colour**

Pink — Dark Red

2) **Firmness**– ***as defined by the resistance of the tomato to being squeezed***

Not firm — Very firm

3) **Ripeness**– ***as defined by the readiness of the tomato to be consumed***

Under ripe — Over Ripe

4) **Aroma**- ***as defined by the scent produced by the tomato***

Unpleasant — Pleasant

5) **Crunchiness**- ***as defined by the noise and resistance of the tomato when bitten into***

Flaccid — Crisp

6) Sweetness

Not Sweet — Very Sweet

7) Acidity

Not acidic — Acidic

8) Moistness

Dry — Very Watery

9) Flavour- ***as defined by the taste of the tomato***

Not flavoursome — Flavoursome

10) Overall Opinion

Dislike — Like

Thank you for your time. Please press your light to request your next sample

Test 2

Please score your samples on the line scales below labelling 'A' for sample A, 'B' for sample B and 'C' for sample C :

1) **Colour**

Pink ——————————————————— Dark Red

2) **Firmness**– ***as defined by the resistance of the tomato to being squeezed***

Not firm ——————————————————— Very firm

3) **Ripeness**– ***as defined by the readiness of the tomato to be consumed***

Under ripe ——————————————————— Over Ripe

4) **Aroma**- ***as defined by the scent produced by the tomato***

Unpleasant ——————————————————— Pleasant

5) **Crunchiness**- ***as defined by the noise and resistance of the tomato when bitten into***

Flaccid ——————————————————— Crisp

6) Sweetness

Not Sweet

Very Sweet

7) Acidity

Not acidic

Acidic

8) Moistness

Dry

Very Watery

9) Flavour- ***as defined by the taste of the tomato***

Not flavoursome

Flavoursome

10) Overall Opinion

Dislike

Like

Thank you for your time. Please press your light to request your next sample

Test 3

Please score your samples on the line scales below labelling 'A' for sample A, 'B' for sample B and 'C' for sample C :

1) **Colour**

Pink

Dark Red

2) **Firmness**– ***as defined by the resistance of the tomato to being squeezed***

Not firm

Very firm

3) **Ripeness** – ***as defined by the readiness of the tomato to be consumed***

Under ripe

Over Ripe

4) **Aroma**- ***as defined by the scent produced by the tomato***

Unpleasant

Pleasant

5) **Crunchiness**- ***as defined by the noise and resistance of the tomato when bitten into***

Flaccid

Crisp

6) Sweetness

Not Sweet — Very Sweet

7) Acidity

Not acidic — Acidic

8) Moistness

Dry — Very Watery

9) Flavour- ***as defined by the taste of the tomato***

Not flavoursome — Flavoursome

10) Overall Opinion

Dislike — Like

Thank you for your time. Please press your light to request your next sample

Test 4

Please score your samples on the line scales below labelling 'A' for sample A, 'B' for sample B and 'C' for sample C :

1) **Colour**

Pink — Dark Red

2) **Firmness**– ***as defined by the resistance of the tomato to being squeezed***

Not firm — Very firm

3) **Ripeness**– ***as defined by the readiness of the tomato to be consumed***

Under ripe — Over Ripe

4) **Aroma**- ***as defined by the scent produced by the tomato***

Unpleasant — Pleasant

5) **Crunchiness**- ***as defined by the noise and resistance of the tomato when bitten into***

Flaccid — Crisp

6) Sweetness

Not Sweet | Very Sweet

7) Acidity

Not acidic | Acidic

8) Moistness

Dry | Very Watery

9) Flavour- ***as defined by the taste of the tomato***

Not flavoursome | Flavoursome

10) Overall Opinion

Dislike | Like

Thank you for your time.
Please press your light to inform the researcher you have finished.

Appendix B: Photographs of Research

Figure 74 Tomatoes from Chapter 5 at Day 11. Tomatoes were stored at RTRT, SCRT RTF and SCF (from left to right). Tomatoes from RTRT are dark red and those from SCF are light red, while those from SCRT and RTF appear similar in colour.

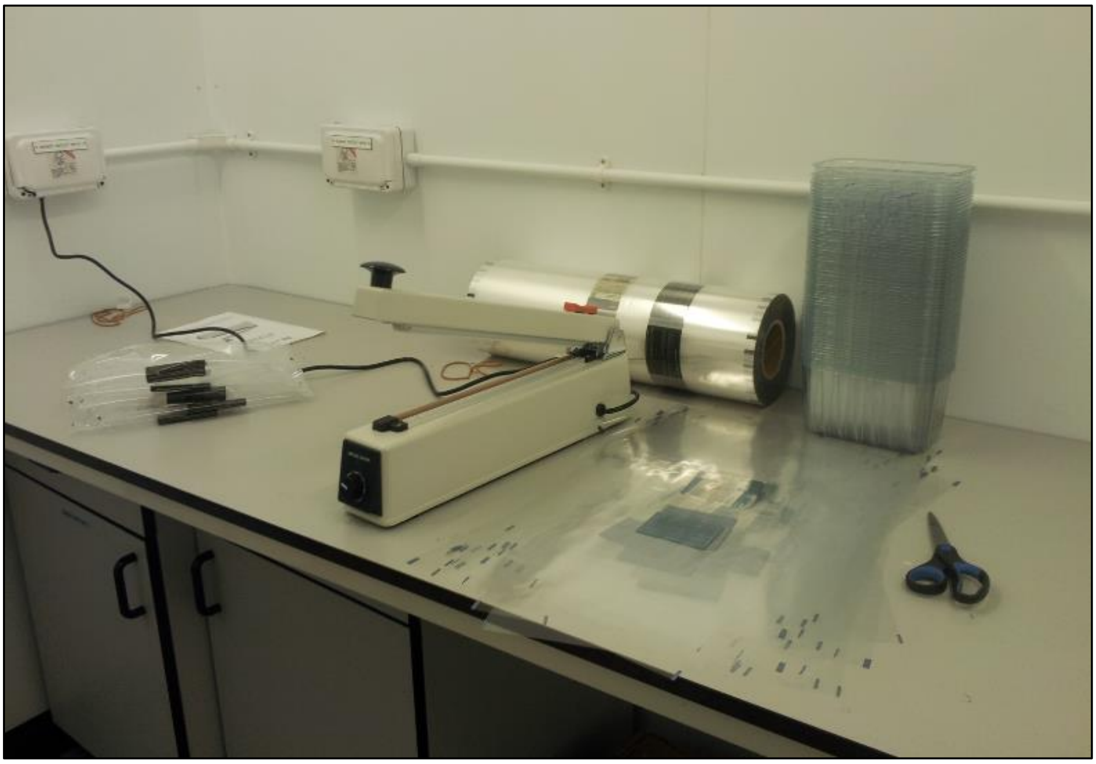

Figure 75 Equipment Used for Packaging Tomatoes during Chapter 6. Equipment included heat sealer, and ASDA's polypropylene wrap and punnets for packaging tomatoes at Newcastle University.

Figure 76 Example of Polypropylene Wrap Used during Chapter 6. Packaging was assembled at Newcastle University at the same time as tomatoes were packaged during the supply chain.

Figure 77 Pictures of Tomatoes being Weighed into 750g Punnets during Chapter 6. Tomatoes were packaged at Newcastle University.

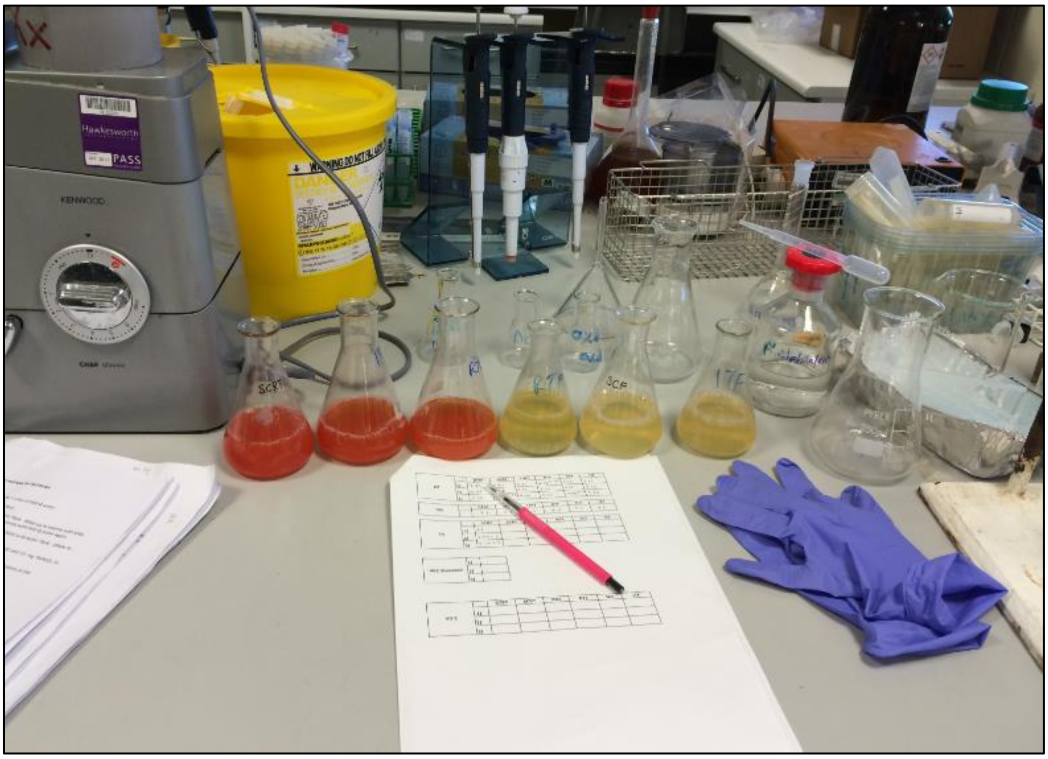

Figure 78 Tomato Supernatant used for Analysis of Chemical Constitutes during Experiments Described in Chapter 6. On the left is the dark orange supernatant from post-sale RT tomatoes, compared with the lighter yellow supernatant of the tomatoes from post-sale F treatments

Figure 79 Picture of Tomato from Post-sale F Treatment Suffering from Anthracnose during Experiments described in Chapter 6.

Figure 80 Picture of Tomato from Post-sale RT Treatment Suffering from Anthracnose during Experiments described in Chapter 6

Figure 81 Picture of Tomatoes from Post-sale F Treatment Suffering from Rhizopus Rot during Experiments described in Chapter 6.

Figure 82 Tomatoes from Post-sale RT Treatment with Skin Wrinkling during Experiments described in Chapter 6.

Appendix C: Tables from Chapter 2

Table 25 Probability for the Deformation, Penetration, Total Soluble Solids, Titratable Acidity and pH of Nectarines, Peaches and Plums. Shop bought fruits were kept at either (RT) (22˚C) or refrigerator (F) (6˚C) temperature. Data was analysed by repeated measures GLM.

		Probability				
Fruit	**Source of Variation**	**Deformation (N/mm)**	**Penetration (N)**	**TSS (°Brix)**	**Titratable Acidity (Malic acid g/100g FW)**	**pH**
Nectarines	**Treatment**	<0.001	<0.001	0.002	0.354	0.239
	Day	0.592	0.001	0.076	0.552	0.854
	Day x Treatment	0.007	0.358	<0.001	0.688	0.273
Peaches	**Treatment**	<0.001	0.001	0.327	0.588	0.457
	Day	0.855	0.798	0.873	0.824	0.663
	Day x Treatment	0.035	<0.001	0.089	0.379	0.409
Plums	**Treatment**	<0.001	0.026	0.556	0.019	0.693
	Day	0.023	0.015	0.244	0.005	0.119
	Day x Treatment	<0.001	0.652	0.741	0.006	0.148

Table 26 Probability for the Weight loss (%) of Green Grapes, Red Grapes, Strawberries, Nectarines, Peaches, Plums, Mandarins, Round Salad Tomatoes, Cherry Tomatoes and Plum Tomatoes. Shop bought fruit was kept at either room (RT) (22˚C) or refrigerator (F) (6˚C) temperature. Data was analysed by repeated measures GLM.

	Weight Loss (%)									
	Probability									
Source of Variation	**Green Grapes**	**Red Grapes**	**Strawberries**	**Nectarines**	**Peaches**	**Plums**	**Mandarins**	**Round Salad Tomatoes**	**Cherry Tomatoes**	**Plum Tomatoes**
Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Day	0.976	0.443	0.862	0.286	0.605	0.437	0.064	0.050	0.545	0.713
Day x Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.062	<0.001	0.042

Table 27 Probability for the Deformation, Penetration, Total Soluble Solids, Titratable Acidity and pH of Strawberries, Red Grapes and Green Grapes. Shop bought fruit were kept at either (RT) (22˚C) or refrigerator (F) (6˚C) temperature. Data was analysed by repeated measures GLM. *Data not recorded.

	Probability					
Fruit	**Source of Variation**	**Deformation (N/mm)**	**Penetration (N)**	**TSS (°Brix)**	**Titratable Acidity (Tartaric acid g/100g FW)**	**pH**
Green Grapes	**Treatment**	<0.001	0.030	<0.001	0.088	0.271
	Day	<0.001	<0.001	<0.001	0.539	0.131
	Day x Treatment	<0.001	0.042	0.306	0.891	0.925
Red Grapes	**Treatment**	<0.001	0.012	<0.001	0.001	0.689
	Day	0.479	0.025	0.769	0.619	0.279
	Day x Treatment	<0.001	0.049	0.001	0.182	0.198
Strawberry	**Treatment**	0.724	0.321	*	*	*
	Day	0.327	0.025	*	*	*
	Day x Treatment	0.020	0.042	*	*	*

Table 28 Probability for the Total Soluble Solids, Titratable Acidity and pH of Round Salad Tomatoes and Mandarins. Shop bought fruit were kept at either room (RT) (22˚C) or refrigerator (F) (6˚C) temperature. Data was analysed by repeated measures GLM.

		TSS (°Brix)	Citric Acid (g/100g FW)	pH
Fruit	**Source of Variation**	**Probability**		
Round Salad Tomatoes	**Treatment**	0.580	0.283	<0.001
	Day	0.499	0.427	0.858
	Day x Treatment	0.919	0.589	0.033
Mandarins	**Treatment**	0.456	0.010	0.687
	Day	0.497	0.467	0.387
	Day x Treatment	0.980	0.092	0.998

Table 29 Probability for the Deformation, Penetration, Total Soluble Solids, Titratable Acidity and pH of Cherry Tomatoes and Plum Tomatoes. Shop bought fruit were kept at either room (RT) (22˚C) or refrigerator (F) (6˚C) temperature. Data was analysed by repeated measures GLM.

Fruit	Source of Variation	Deformation (N/mm)	Penetration (N)	TSS (°Brix)	Titratable Acidity (Citric acid g/100g FW)	pH
		Probability				
Cherry Tomatoes	Treatment	<0.001	<0.001	0.027	0.019	0.006
	Day	0.318	0.072	0.953	0.808	0.900
	Day x Treatment	0.741	0.178	0.497	0.888	0.098
Plum Tomatoes	Treatment	0.048	0.137	0.700	0.322	0.205
	Day	0.753	0.001	0.988	0.634	0.403
	Day x Treatment	0.144	0.004	0.781	0.231	0.250

Appendix D: Tables from Chapter 3

Table 30 Mean Sensory Scores for Tomatoes that were analysed for Sensory Firmness. Shop bought tomatoes were kept at either 23°C (RT) or 5°C (F) for four days. Numbers in brackets represent standard error

Treatment	Sensory Category								
	Overall Opinion	Colour	Ripeness	Moistness	Aroma	Sweetness	Flavour	Firmness	Crunchiness
F	7.50 (0.54)	6.07 (0.38)	6.66 (0.43)	7.83 (0.45)	7.32 (0.40)	7.99 (0.46)	6.47 (0.48)	8.32 (0.49)	9.43 (0.37)
RT	7.70 (0.51)	10.03 (0.38	8.76 (0.41)	8.46 (0.42)	8.51 (0.37)	7.12 (0.44)	7.60 (0.52)	7.77 (0.51)	7.53 (0.43)

Table 31 Mean Firmness Scores for Tomatoes. Whole fruit and half fruit deformation (N/mm), and whole fruit and quarter fruit penetration (N) of shop bought tomatoes kept at 23°C (RT) or 5°C (F) for four days. Numbers in brackets represent standard error. Data was analysed by ANOVA.

Treatment	Whole Fruit Deformation (N/mm)	Half Fruit Deformation (N/mm)	Whole Fruit Penetration (N)	Quarter Fruit Penetration (N)
F	3.02 (0.12)	3.72 (0.16)	13.95 (0.62)	6.94 (0.38)
RT	2.45 (0.12)	3.08 (0.12)	11.47 (0.47)	7.00 (0.42)
p-value	0.001	0.002	0.002	0.510

Table 32 Mean Sensory Scores and the Probability for the Mean Sensory Scores of Tomatoes. Shop bought tomatoes were kept at either RT (23˚C) or F (5˚C) for four days. Tomatoes were compared for sensory outcome investigating the effect of treatment, and also whether sample order had an effect of sensory outcome by giving participants samples either mixed or alone. Numbers in brackets represent standard error. Data was analysed by ANOVA.

Treatment	Sensory Category								
	Overall Opinion	Colour	Ripeness	Moistness	Aroma	Sweetness	Flavour	Firmness	Crunchiness
F-Mixed	7.21 (0.81)	5.27 (0.39)	6.44 (0.66)	7.46 (0.66)	7.03 (0.54)	7.76 (0.68)	6.56 (0.71)	8.35 (0.76)	9.40 (0.50)
F-Only	7.78 (0.72)	6.87 (0.62)	6.88 (0.57)	8.19 (0.62)	7.62 (0.59)	8.21 (0.63)	6.37 (0.67)	8.29 (0.64)	9.46 (0.57)
RT- Mixed	7.85 (0.68)	11.36 (0.29)	9.06 (0.62)	7.91 (0.62)	8.77 (0.62)	7.61 (0.61)	8.43 (0.68)	7.71 (0.79)	8.25 (0.68)
RT- Only	7.54 (0.77)	9.55 (0.51)	8.48 (0.55)	9.015 (0.56)	8.25 (0.40)	6.62 (0.63)	6.77 (0.75)	7.82 (0.67)	6.82 (0.54)
Source of Variation	**Probability**								
RT-mixed vs F-mixed	0.626	<0.001	0.004	0.427	0.012	0.641	0.112	0.398	0.115
RT-only vs F-only	0.781	0.006	0.051	0.364	0.282	0.058	0.859	0.614	0.005

Appendix E: Tables from Chapter 4

Table 33 Mean Sensory Scores for Tomatoes. Fruit had been kept at F (5˚C) and analysed under blue light filter (F + Blue Light Filter) or under normal light (F + Normal Light), or kept at RT (23˚C) and analysed under blue light filter (RT + Blue Light Filter) or normal light (RT + Normal Light) and analysed by participants ranging from 18-35 years of age. Standard error is shown in brackets. Data was analysed by GLM.

Treatment + lighting condition	Sensory Category									
	Overall Opinion	Colour	Ripeness	Moistness	Aroma	Sweetness	Flavour	Acidity	Firmness	Crunchiness
F + Blue Light Filter	6.27 (0.37)	6.74 (0.37)	7.70 (0.35)	7.82 (0.34)	7.28 (0.28)	6.22 (0.34)	6.56 (0.40)	5.00 (0.36)	8.12 (0.37)	8.75 (0.35)
F + Normal Light	6.33 (0.45)	7.38 (0.41)	7.29 (0.36)	7.30 (0.41)	7.57 (0.40)	5.75 (0.41)	6.00 (0.46)	6.89 (0.47)	8.87 (0.45)	7.76 (0.41)
RT + Blue Light Filter	7.60 (0.49)	10.13 (0.32)	8.59 (0.33)	8.55 (0.34)	9.10 (0.35)	7.25 (0.39)	7.63 (0.44)	5.75 (0.40)	7.97 (0.41)	7.91 (0.38)
RT + Normal Light	7.35 (0.49)	10.60 (0.42)	8.36 (0.38)	8.63 (0.38)	8.51 (0.39)	6.93 (0.43)	7.27 (0.46)	7.03 (0.47)	7.81 (0.44)	7.75 (0.41)

Table 34 Mean Sensory Scores for Tomatoes. Fruits had been kept at F (5˚C) and analysed under blue light filter (F + Blue Light Filter) or under normal light (F + Normal Light), or kept at RT (23˚C) and analysed under blue light filter (RT + Blue Light Filter) or normal light (RT + Normal Light) and analysed by participants ranging from 45+ years of age. Standard error is shown in brackets. Data was analysed by GLM.

Treatment	Sensory Category									
	Overall Opinion	Colour	Ripeness	Moistness	Aroma	Sweetness	Flavour	Acidity	Firmness	Crunchiness
F + Blue Light Filter	7.50 (0.44)	7.10 (0.48)	6.69 (0.42)	8.30 (0.40)	8.04 (0.36)	6.92 (0.42)	7.06 (0.45)	7.31 (0.43)	8.82 (0.43)	8.78 (0.42)
F + Normal Light	7.53 (0.54)	6.77 (0.55)	6.60 (0.50)	7.60 (0.50)	7.77 (0.43)	6.71 (0.46)	7.65 (0.55)	8.27 (0.49)	9.24 (0.57)	8.93 (0.53)
RT + Blue Light Filter	7.05 (0.42)	9.04 (0.52)	7.71 (0.42)	8.65 (0.34)	8.10 (0.39)	7.41 (0.36)	7.08 (0.42)	7.98 (0.41)	7.13 (0.46)	7.51 (0.37)
RT + Normal Light	8.16 (0.53)	9.41 (0.57)	8.26 (0.57)	8.71 (0.45)	8.42 (0.43)	6.80 (0.47)	8.04 (0.59)	7.99 (0.48)	7.94 (0.56)	7.99 (0.60)

Appendix F: Tables from Chapter 5

Table 35 Mean Sensory Scores of Tomatoes. Fruit were stored for 7 days at either RT (23˚C) or SC (average 12˚C), and until day 11 at RTF, SCF, RTRT or SCRT.

		Sensory Category								
Day	**Treatment**	**Overall Opinion**	**Colour**	**Ripeness**	**Moistness**	**Sweetness**	**Aroma**	**Flavour**	**Firmness**	**Crunchiness**
7	**RT**	9.17 (0.25)	11.34 (0.15)	10.37 (0.16)	10.15 (0.16)	9.05 (0.21)	9.73 (0.19)	9.45 (0.22)	7.18 (0.23)	7.18 (0.19)
	SC	7.33 (0.24)	6.00 (0.16)	6.12 (0.18)	7.90 (0.20)	6.60 (0.25)	8.02 (0.19)	7.50 (0.24)	9.79 (0.22)	9.97 (0.20)
11	**RTF**	8.99 (0.26)	10.23 (0.20)	9.46 (0.22)	9.78 (0.20)	8.53 (0.17)	9.41 (0.23)	8.97 (0.24)	8.04 (0.28)	7.47 (0.24)
	RTRT	9.18 (0.25)	12.10 (0.15)	11.03 (0.22)	10.29 (0.21)	8.66 (0.28)	10.39 (0.35)	9.37 (0.26)	6.67 (0.28)	6.53 (0.25)
	SCF	6.45 (0.26)	5.77 (0.22)	5.21 (0.21)	7.26 (0.25)	6.07 (0.25)	7.10 (0.21)	6.60 (0.28)	10.14 (0.25)	10.11 (0.25)
	SCRT	9.10 (0.26)	9.82 (0.18)	9.29 (0.17)	9.68 (0.19)	8.64 (0.25)	9.42 (0.22)	9.20 (0.25)	8.20 (0.25)	7.37 (0.24)

Table 36 Probability for the Mean Sensory Scores of Tomatoes. Fruit were stored at either RT (23˚C) or SC (average 12˚C) for 7 days; and for a further four days at RTF, SCF, RTRT or SCRT (day 11). Data at day 7 was analysed by ANOVA, and day 11 data was analysed by GLM.

		Sensory Category								
Day	**Source of Variation**	**Overall Opinion**	**Colour**	**Ripeness**	**Moistness**	**Sweetness**	**Aroma**	**Flavour**	**Firmness**	**Crunchiness**
		Probability								
7	**Treatment**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
11	**Pre-sale Treatment**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001
	Post-sale Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Pre-sale x Post-sale Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.438	0.001

Table 37 Probability for the Mean Colour Values of Tomatoes. L, a* and b* values of tomatoes after being stored at either for 7 days at RT (23˚C) or SC (average 12˚C); and for a further four days at RTF, RTRT, SCF or SCRT (day 11). Day 7 data was analysed by ANOVA, and day 11 data was analysed by GLM.

		L	**a***	**b***
Day	**Source of Variation**	**Probability**		
7	**Treatment**	0.035	<0.001	<0.001
	Pre-sale Treatment	<0.001	0.001	<0.001
11	**Post-sale Treatment**	0.073	0.679	0.101
	Pre-sale x Post-sale Treatment	0.320	0.660	0.131

Table 38 Probability for the Mean Tomato Firmness. Firmness was measures as penetration (N), and deformation (N/mm) of tomatoes after being stored for 7 days at RT (23˚C) or SC (average 12˚C); and for a further four days at RTF, RTRT, SCF or SCRT (day 11). Day 7 data was analysed by ANOVA and day 11 data was analysed by GLM.

		Penetration of whole fruit (N)	Deformation of whole fruit (N/mm)
Day	**Source of Variation**	**Probability**	
7	**Treatment**	<0.001	0.254
11	**Pre-sale Treatment**	<0.001	0.383
	Post-Sale Treatment	0.572	0.470
	Pre-sale x Post-sale Treatment	0.830	0.543

Table 39 Probability for the Mean Surviving Tomatoes (%). Fruits were stored for 7 days at RT (23˚C) or SC (average 12˚C), and at RTF, RTRT, SCF or SCRT for the remainder of the study. Survival calculation using the Kaplan-Meier Estimator (Kaplan and Meier, 1958) was used to determine shelf life differences.

Treatment	RTF	RTRT	SCF	SCRT
p-value from chi-squared distribution table with 1 degree of freedom				
RTF		p<0.001	p<0.001	p<0.001
RTRT	p<0.001		p<0.001	p=0.200
SCF	p<0.001	p<0.001		p<0.001
SCRT	P<0.001	p=0.200	p<0.001	

Appendix G: Tables from Chapter 6

Table 40 Mean Sensory Scores at Day 7 for Tomatoes Harvested in May, July and September. Fruits were stored at IT (15˚C), RT (23˚C) or SC (average 12˚C). Numbers in brackets represent standard error.

Month	Treatment	Sensory Category									
		Overall Opinion	Colour	Ripeness	Aroma	Moistness	Sweetness	Flavour	Acidity	Firmness	Crunchiness
May	IT	7.95 (0.29)	8.04 (0.21)	7.80 (0.21)	8.32 (0.20)	8.32 (0.21)	7.35 (0.26)	7.89 (0.27)	8.15 (0.23)	8.38 (0.25)	9.11 (0.23)
	RT	8.71 (0.28)	11.30 (0.17)	10.24 (0.20)	9.30 (0.23)	10.06 (0.20)	8.25 (0.26)	8.55 (0.25)	7.33 (0.25)	6.75 (0.27)	6.71 (0.24)
	SC	6.37 (0.28)	5.62 (0.17)	5.57 (0.20)	7.34 (0.23)	7.20 (0.20)	6.01 (0.26)	6.52 (0.25)	8.79 (0.25)	9.76 (0.27)	10.02 (0.24)
	Average	7.68 (0.28)	8.32 (0.18)	7.87 (0.20)	8.32 (0.22)	8.53 (0.21)	7.21 (0.26)	7.66 (0.26)	8.09 (0.24)	8.29 (0.27)	8.61 (0.24)
July	IT	7.08 (0.28)	7.33 (0.22)	6.72 (0.23)	8.43 (0.24)	8.10 (0.22)	6.59 (0.23)	7.01 (0.26)	7.19 (0.28)	9.50 (0.24)	10.19 (0.21)
	RT	8.70 (0.30)	11.19 (0.18)	10.11 (0.21)	9.85 (0.24	10.43 (0.18)	8.24 (0.28)	8.47 (0.30)	5.91 (0.25)	6.90 (0.26)	7.00 (0.28)

	SC	6.80 (0.30)	5.73 (0.24)	5.59 (0.25)	7.88 (0.25)	7.68 (0.23)	6.46 (0.26)	6.72 0.29)	7.39 (0.31)	9.40 (0.26)	10.42 (0.21)
	Average	7.53 (0.29)	8.08 (0.21)	7.47 (0.23)	8.72 (0.25)	8.73 (0.21)	7.10 (0.25)	7.40 (0.28)	6.83 (0.28)	8.60 (0.25)	9.20 (0.24)
September	**IT**	7.84 (0.29)	7.80 (0.23)	7.16 (0.21)	8.17 (0.27)	8.26 (0.20)	7.22 (0.27)	7.77 (0.26)	7.50 (0.27)	9.75 (0.21)	9.73 (0.19)
	RT	8.68 (0.28)	11.73 (0.14)	10.33 (0.17)	9.60 (0.24)	9.89 (0.19)	8.44 (0.25)	8.64 (0.26)	6.06 (0.24)	6.77 (0.26)	6.94 (0.21)
	SC	5.89 (0.30)	5.44 (0.26)	5.26 (0.25)	6.57 (0.28)	7.04 (0.22)	5.38 (0.25)	6.03 (0.26)	8.09 (0.31)	10.35 (0.22)	10.68 (0.20)
	Average	7.47 (0.29)	8.32 (0.20)	7.59 (0.21)	8.11 (0.26)	8.40 (0.20)	7.02 (0.25)	7.48 (0.26)	7.21 (0.27)	8.96 (0.23)	9.11 (0.20)
All Tomato Season	**IT**	7.61 (0.17)	7.71 (0.13)	7.20 (0.13)	8.30 (0.14)	8.22 (0.12)	7.05 (0.15)	7.54 (0.15)	7.59 (0.15)	9.24 (0.14)	9.70 (0.12)
	RT	8.70 (0.17)	11.41 (0.09)	10.23 (0.11)	9.59 (0.14)	10.13 (0.11)	8.31 (0.15)	8.55 (0.16)	6.39 (0.15)	6.81 (0.15)	6.89 (0.14)
	SC	6.35 (0.18)	5.59 (0.14)	5.47 (0.14)	7.26 (0.15)	7.31 (0.13)	5.95 (0.15)	6.42 (0.16)	8.06 (0.17)	9.84 (0.14)	10.39 (0.13)

Table 41 Probability for the Sensory Scores Awarded to Tomatoes kept at IT (15˚C), RT (23˚C) or SC (average 12˚C) Treatment. Fruits were kept at these treatments for 7 days. Data was analysed by GLM.

	Sensory Category									
	Overall Opinion	**Colour**	**Ripeness**	**Aroma**	**Moistness**	**Sweetness**	**Flavour**	**Acidity**	**Firmness**	**Crunchiness**
Source of Variation	**Probability**									
Month	0.680	0.277	0.082	0.007	0.132	0.669	0.511	<0.001	0.005	0.005
Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Month x Treatment	0.047	0.099	0.065	0.084	0.273	0.007	0.073	0.659	0.007	0.168

Table 42 Mean Sensory Scores at Day 11 for Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at RT (23˚C), IT (15˚C) or SC (average 12˚C), and for four days of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets represent standard error.

Month	Treatment	Overall Opinion	Colour	Ripeness	Moistness	Aroma	Sweetness	Flavour	Acidity	Firmness	Crunchiness
May	ITF	7.76 (0.39)	7.35 (0.25)	7.37 (0.28)	8.01 (0.26)	8.25 (0.30)	6.77 (0.33)	7.56 (0.36)	7.82 (0.33)	8.81 (0.33)	9.33 (0.30)
	RTF	7.91 (0.39)	9.31 (0.28)	8.48 (0.27)	9.10 (0.30)	9.07 (0.27)	7.57 (0.32)	7.65 (0.35)	6.71 (0.32)	8.16 (0.36)	7.77 (0.27)
	SCF	6.17 (0.29)	5.15 (0.23)	5.59 (0.24)	7.52 (0.23)	6.63 (0.27)	6.25 (0.25)	6.50 (0.29)	7.81 (0.28)	8.73 (0.28)	9.93 (0.27)
	ITRT	8.10 (0.39)	10.62 (24)	9.58 (0.23)	9.55 (0.28)	8.44 (0.32)	8.17 (0.34)	8.19 (0.35)	7.00 (0.30)	7.09 (0.32)	6.19 (0.32)
	RTRT	7.67 (0.37)	10.57 (0.24)	9.94 (0.24)	9.33 (0.25)	9.01 (0.27)	7.36 (0.32)	7.81 (0.34)	6.84 (0.29)	6.74 (0.31)	6.99 (0.29)
	SCRT	8.37 (0.45)	9.40 (0.34)	8.60 (0.33)	8.78 (0.33)	8.16 (0.33)	7.43 (0.38)	7.95 (0.42)	7.51 (0.36)	7.27 (0.37)	8.55 (0.36)

	Average	7.66 (0.38)	8.73 (0.26)	8.26 (0.27)	8.72 (0.27)	8.26 (0.30)	7.26 (0.32)	7.61 (0.35)	7.28 (0.32)	7.80 (0.33)	8.13 (0.30)
July	**ITF**	7.53 (0.42)	6.30 (0.35)	6.39 (0.38)	8.42 (0.34)	8.17 (0.31)	6.73 (0.37)	7.06 (0.41)	7.83 (0.40)	9.97 (0.36)	10.05 (0.32)
	RTF	7.11 (0.52)	8.99 (0.36)	8.00 (0.34)	9.00 (0.32)	8.55 (0.31)	7.54 (0.37)	7.45 (0.44)	7.37 (0.40)	7.67 (0.40)	8.17 (0.36)
	SCF	6.34 (0.46)	4.57 (0.28)	5.04 (0.33)	7.68 (0.30)	7.51 (0.30)	5.78 (0.40)	6.00 (0.41)	8.52 (0.44)	10.42 (0.36)	10.80 (0.29)
	ITRT	8.71 (0.49)	10.57 (0.30)	8.52 (0.25)	9.40 (0.26)	9.64 (0.33)	7.22 (0.40)	8.66 (0.40)	7.96 (0.43)	8.03 (0.42)	7.35 (0.35)
	RTRT	8.54 (0.45)	11.36 (0.30)	9.23 (0.33)	9.88 (0.27)	9.60 (0.30)	8.11 (0.39)	8.92 (0.41)	6.50 (0.44)	7.07 (0.44)	7.19 (0.34)
	SCRT	8.54 (0.44)	9.28 (0.35)	8.20 (0.30)	9.37 (0.24)	9.22 (0.35)	7.23 (0.36)	8.43 (0.39)	7.73 (0.40)	8.05 (0.41)	8.68 (0.32)
	Average	7.80 (0.47)	8.51 (0.32)	7.56 (0.32)	8.96 (0.29)	8.78 (0.32)	7.10 (0.38)	7.75 (0.41)	7.65 (0.42)	8.53 (0.40)	8.71 (0.33)
September	**ITF**	8.17 (0.35)	7.99 (0.26)	7.83 (0.31)	8.85 (0.28)	8.86 (0.33)	7.26 (0.32)	8.40 (0.37)	7.42 (0.40)	9.68 (0.32)	8.82 (0.29)

	RTF	8.72 (0.42)	10.95 (0.24)	9.89 (0.26)	9.82 (0.32)	9.32 (0.36)	8.57 (0.36)	9.13 (0.41)	6.70 (0.40)	6.62 (0.38)	6.72 (0.37)
	SCF	7.45 (0.44)	6.28 (0.33)	6.19 (0.36)	7.54 (0.36)	7.91 (0.39)	6.23 (0.35)	7.79 (0.39)	8.14 (0.46)	9.46 (0.35)	10.37 (0.26)
	ITRT	8.78 (0.41)	10.79 (0.30)	9.91 (0.27)	10.22 (0.26)	9.73 (0.34)	8.47 (0.43)	9.44 (0.35)	6.26 (0.34)	7.41 (0.41)	6.77 (0.38)
	RTRT	8.75 (0.43)	12.08 (0.17)	10.38 (0.28)	10.38 (0.28)	9.60 (0.34)	9.04 (0.39)	9.40 (0.33)	5.66 (0.39)	7.04 (0.41)	6.33 (0.39)
	SCRT	9.55 (0.37)	10.21 (0.28)	8.80 (0.30)	9.64 (0.28)	9.27 (0.35)	8.27 (0.36)	9.57 (0.37)	7.04 (0.38)	8.27 (0.38)	7.90 (0.34)
	Average	8.57 (0.40)	9.72 (0.26)	8.83 (0.30)	9.40 (0.30)	9.11 (0.35)	7.97 (0.37)	8.95 (0.37)	6.87 (0.40)	8.08 (0.37)	7.82 (0.34)
All Tomato Season	**ITF**	7.81 (0.23)	7.22 (0.17)	7.20 (0.19)	8.39 (0.17)	8.41 (0.18)	6.91 (0.20)	7.66 (0.22)	7.70 (0.21)	9.43 (0.20)	9.40 (0.18)
	RTF	7.92 (0.26)	9.7 (0.18)	8.75 (0.18)	9.28 (0.18)	8.99 (0.18)	7.85 (0.20)	8.03 (0.23)	6.90 (0.21)	7.56 (0.22)	7.58 (0.19)
	SCF	6.66 (0.26)	5.33 (0.19)	5.6 (0.20)	7.58 (0.19)	7.36 (0.21)	6.08 (0.21)	6.76 (0.24)	8.16 (0.25)	9.55 (0.22)	10.38 (0.18)

ITRT	8.48 (0.25)	10.66 (0.16)	9.35 (0.15)	9.69 (0.16)	9.17 (0.20)	7.97 (0.23)	8.69 (0.22)	7.07 (0.21)	7.46 (0.22)	6.71 (0.20)
RTRT	8.22 (0.24)	11.22 (0.15)	9.86 (0.16)	9.78 (0.16)	9.35 (0.18)	8.05 (0.21)	8.58 (0.22)	6.41 (0.21)	6.92 (0.22)	6.86 (0.19)
SCRT	8.82 (0.25)	9.62 (0.19)	8.53 (0.18)	9.26 (0.17)	8.89 (0.20)	7.64 (0.21)	8.65 (0.23)	7.43 (0.22)	7.86 (0.22)	8.38 (0.20)

Table 43 Mean Sensory Scores at Day 15 for Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for eight days of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets represent standard error.

		Sensory Category									
Month	**Treatment**	**Overall Opinion**	**Colour**	**Ripeness**	**Moistness**	**Aroma**	**Sweetness**	**Flavour**	**Acidity**	**Firmness**	**Crunchiness**
May	**ITF**	6.90 (0.33)	6.33 (0.21)	6.77 (0.25)	7.56 (0.25)	7.59 (0.28)	6.75 (0.30)	6.74 (0.29)	8.36 (0.31)	9.19 (0.30)	9.29 (0.24)
	RTF	8.12 (0.30)	8.59 (0.26)	8.65 (0.26)	8.93 (0.26)	8.19 (0.23)	7.63 (0.28)	7.72 (0.30)	7.84 (0.30)	7.56 (0.30)	7.86 (0.27)
	SCF	5.22 (0.32)	4.92 (0.27)	4.80 (0.26)	6.52 (0.33)	6.24 (0.31)	5.50 (0.30)	5.47 (0.32)	7.31 (0.39)	9.67 (0.33)	10.33 (0.33)
	ITRT	8.85 (0.30)	10.98 (0.20)	9.76 (0.22)	9.94 (0.20)	9.16 (0.22)	8.56 (0.30)	8.52 (0.28)	7.28 (0.29)	7.26 (0.29)	6.95 (0.28)
	RTRT	9.52 (0.28)	11.02 (0.20)	10.21 (0.20)	10.36 (0.21)	8.88 (0.27)	9.07 (0.25)	9.09 (0.27)	6.93 (0.29)	6.63 (0.30)	6.70 (0.30)
	SCRT	8.20 (0.38)	11.00 (0.23)	9.75 (0.27)	9.56 (0.26)	9.26 (0.28)	7.73 (0.34)	7.74 (0.37)	8.10 (0.32)	6.97 (0.33)	6.89 (0.33)
	Average	7.80 (0.32)	8.81 (0.23)	8.32 (0.24)	8.81 (0.25)	8.22 (0.26)	7.54 (0.30)	7.55 (0.31)	7.63 (0.31)	7.88 (0.31)	8.00 (0.29)

July	**ITF**	8.55 (0.40)	9.27 (0.30)	8.14 (0.32)	8.45 (0.29)	9.32 (0.30)	7.52 (0.37)	8.08 (0.38)	7.29 (0.35)	7.83 (0.37)	8.77 (0.33)
	RTF	8.92 (0.41)	9.62 (0.31)	8.12 (0.29)	9.11 (0.26)	9.29 (0.33)	8.03 (0.40)	8.51 (0.40)	7.13 (0.38)	8.17 (0.36)	8.07 (0.34)
	SCF	7.66 (0.41)	6.68 (0.39)	6.79 (0.34)	8.40 (0.33)	8.25 (0.34)	6.62 (0.40)	7.25 (0.38)	7.10 (0.41)	9.43 (0.35)	9.18 (0.35)
	ITRT	9.09 (0.42)	10.28 (0.28)	8.71 (0.27)	9.04 (0.30)	9.30 (0.27)	7.66 (0.38)	8.45 (0.41)	5.97 (0.33)	7.64 (0.36)	7.51 (0.31)
	RTRT	8.47 (0.42)	9.84 (0.37)	8.75 (0.30)	8.90 (0.29)	9.44 (0.35)	8.00 (0.38)	8.26 (0.37)	6.46 (0.33)	7.98 (0.38)	7.44 (0.35)
	SCRT	8.77 (0.42)	9.76 (0.41)	8.22 (0.35)	9.05 (0.30)	8.96 (0.41)	7.46 (0.42)	8.17 (0.38)	6.62 (0.40)	8.05 (0.37)	7.77 (0.33)
	Average	8.58 (0.41)	9.24 (0.34)	8.12 (0.31)	8.82 (0.30)	9.09 (0.33)	7.55 (0.39)	8.12 (0.39)	6.76 (0.37)	8.18 (0.36)	8.12 (0.34)
September	**ITF**	7.40 (0.40)	7.60 (0.33)	7.38 (0.33)	7.72 (0.34)	7.94 (0.36)	7.28 (0.39)	7.42 (0.37)	8.00 (0.39)	9.19 (0.35)	9.02 (0.33)
	RTF	8.14 (0.44)	8.82 (0.36)	8.74 (0.35)	9.80 (0.34)	8.54 (0.38)	7.81 (0.42)	8.00 (0.42)	6.20 (0.38)	7.10 (0.43)	6.84 (0.39)

	SCF	6.14 (0.43)	5.93 (0.28)	5.64 (0.35)	7.19 (0.29)	7.48 (0.36)	6.08 (0.39)	6.34 (0.39)	8.13 (0.41)	9.57 (0.38)	10.04 (0.34)
	ITRT	8.65 (0.45)	10.94 (0.30)	10.01 (0.29)	9.92 (0.35)	9.25 (0.39)	7.68 (0.41)	8.59 (0.41)	7.46 (0.41)	7.32 (0.38)	6.24 (0.33)
	RTRT	8.21 (0.45)	11.18 (0.23)	10.09 (0.28)	10.56 (0.26)	8.96 (0.41)	8.28 (0.45)	8.29 (0.40)	6.43 (0.39)	6.78 (0.37)	6.76 (0.36)
	SCRT	8.01 (0.43)	10.80 (0.24)	9.72 (0.28)	10.12 (0.29)	9.19 (0.36)	8.00 (0.45)	8.26 (0.39)	7.20 (0.39)	7.64 (0.40)	6.69 (0.32)
	Average	7.76 (0.43)	9.21 (0.29)	8.60 (0.31)	9.22 (0.31)	8.56 (0.37)	7.52 (0.41)	7.81 (0.40)	7.23 (0.40)	7.93 (0.39)	7.60 (0.34)
All Tomato Season	**ITF**	7.60 (0.22)	7.68 (0.18)	7.40 (0.20)	7.91 (0.18)	8.27 (0.17)	7.16 (0.17)	7.39 (0.20)	7.90 (0.20)	8.73 (0.17)	9.04 (0.20)
	RTF	8.38 (0.22)	8.99 (0.18)	8.50 (0.21)	9.24 (0.18)	8.65 (0.17)	7.81 (0.19)	8.05 (0.20)	7.14 (0.21)	7.63 (0.16)	7.64 (0.21)
	SCF	6.37 (0.24)	5.86 (0.20)	5.77 (0.20)	7.40 (0.20)	7.34 (0.20)	6.08 (0.20)	6.37 (0.24)	7.49 (0.21)	9.55 (0.19)	9.83 (0.21)
	ITRT	8.87 (0.22)	10.74 (0.15)	9.48 (0.19)	9.64 (0.16)	9.23 (0.15)	8.02 (0.18)	8.51 (0.20)	6.90 (0.21)	7.40 (0.16)	6.94 (0.21)

RTRT	8.83 (0.22)	10.69 (0.16)	9.71 (0.20)	9.94 (0.20)	9.08 (0.15)	8.51 (0.19)	8.61 (0.20)	6.64 (0.20)	7.11 (0.15)	6.95 (0.20)
SCRT	8.35 (0.24)	10.49 (0.19)	9.18 (0.21)	9.55 (0.21)	9.13 (0.18)	7.72 (0.20)	8.05 (0.22)	7.28 (0.23)	7.57 (0.17)	7.15 0.22)

Table 44 Probability for the Sensory Scores Awarded to Tomatoes at day 11 and 15. Fruits were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated measures GLM.

Source of Variation	Sensory Category									
	Overall Opinion	Colour	Ripeness	Aroma	Moistness	Sweetness	Flavour	Acidity	Firmness	Crunchiness
	Probability									
Day	0.713	0.275	0.162	0.363	0.533	0.345	0.037	0.619	0.204	0.005
Month	0.006	<0.001	<0.001	<0.001	<0.001	0.015	<0.001	0.025	0.002	<0.001
Post-sale Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Pre-sale Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Day x Month	<0.001	<0.001	0.006	0.007	0.321	0.007	<0.001	<0.001	0.392	0.212
Day x Pre-sale Treatment	0.025	<0.001	0.054	0.266	0.259	0.888	0.295	0.154	0.255	0.001
Day x Post-sale Treatment	0.472	0.792	0.350	0.426	0.051	0.564	0.874	0.908	0.523	0.946
Month x Pre-sale Treatment	0.149	0.278	0.084	0.484	0.012	0.791	0.729	0.145	0.029	0.276
Month x Post-sale Treatment	0.187	<0.001	<0.001	0.336	<0.001	0.018	0.531	0.481	0.045	0.062
Pre-sale Treatment x Post-sale Treatment	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.354	<0.001	<0.001

Table 45 Mean L, a* and b* Values of Tomatoes at Day 0 and 7. Tomatoes were kept at IT (15˚C), RT (23˚C) and SC (average 12˚C) treatments for 7 days. Numbers in brackets represent standard error.

Month	Treatment	Day 0			Day 7		
		L	a*	b*	L	a*	b*
May	IT	63.40 (0.82)	41.12 (1.33)	42.81 (0.46)	51.03 (0.36)	50.79 (0.32)	33.97 (0.35)
	RT	64.69 (1.05)	39.52 (0.18)	43.70 (0.53)	48.15 (0.45)	47.75 (0.39)	29.69 (0.28)
	SC	64.10 (1.06)	40.57 (1.67)	43.63 (0.53)	55.35 (0.56)	50.59 (0.46)	39.06 (0.64)
	Average	64.06 (0.98)	40.40 (1.60)	43.38 (0.51)	51.51 (0.46)	49.71 (0.39)	34.24 (0.44)
July	IT	58.13 (1.39)	23.76 (1.60)	43.26 (0.79)	46.25 (0.79)	43.70 (0.46)	35.61 (0.52)
	RT	56.09 (1.11)	28.97 (1.37)	42.76 (0.78)	41.56 (0.80)	42.66 (0.45)	30.53 (0.84)
	SC	54.61 (1.28)	28.40 (2.16)	41.60 (0.96)	44.37 (0.78)	42.82 (0.53)	33.55 (0.75)
	Average	56.28 (1.26)	27.04 (1.71)	42.54 (0.84)	44.06 (0.79)	43.06 (0.48)	33.23 (0.75)
September	IT	53.94 (0.78)	31.18 (0.15)	37.93 (1.09)	43.83 (0.74)	43.25 (0.50)	33.37 (0.47)
	RT	53.14 (0.54)	32.24 (0.12)	40.30 (0.44)	40.35 (0.55)	41.90 (0.40)	29.66 (0.39)

	SC	52.89 (0.67)	30.38 (1.11)	37.86 (0.51)	47.85 (0.71)	42.41 (0.48)	36.99 (0.45)
	Average	53.32 (0.66)	31.27 (1.28)	38.70 (0.68)	44.01 (0.67)	42.52 (0.46)	33.34 (0.55)
All Tomato Season	**IT**	58.49 (0.81)	32.02 (1.33)	45.76 (0.58)	46.48 (0.53)	45.45 (0.49)	34.16 (0.27)
	RT	58.11 (0.89)	33.70 (1.05)	42.28 (0.39)	42.67 (0.49)	43.58 (0.35)	29.99 (0.29)
	SC	57.20 (0.93)	33.12 (1.24)	41.03 (0.53)	47.92 (0.58)	44.31 (0.44)	35.93 (0.39)

Table 46 Probability for the Mean L, a* and b* Values of Tomatoes from IT (15˚C), RT (23˚C) and SC (average 12˚C). Fruits were kept at these treatments for 7 days. Data was analysed by GLM.

	Day 0			Day 7		
	L	**a***	**b***	**L**	**a***	**b***
Source of Variation	**Probability**					
Month	<0.001	<0.001	<0.001	<0.001	<0.001	0.045
Treatment	0.287	0.454	0.067	<0.001	<0.001	<0.001
Month x Treatment	0.277	0.174	0.167	<0.001	0.015	<0.001

Table 47 Mean L, a* and b* Values of Tomatoes at Day 11 and 15. Tomatoes were stored for 7 days at IT (15°C), RT (23°C) or SC (average 12°C), and for four (day 11) and eight (day 15) days of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets show standard error.

Month	Treatment	Day 11			Day 15		
		L	a*	b*	L	a*	b*
May	ITF	51.60 (0.36)	51.35 (0.36)	34.25 (0.35)	52.17 (0.28)	46.98 (0.40)	34.47 (0.32)
	ITRT	48.84 (0.31)	48.35 (0.32)	29.80 (0.34)	47.77 (0.27)	52.71 (0.42)	27.82 (0.43)
	RTF	49.58 (0.29)	49.42 (0.36)	30.86 (0.35)	50.16 (0.28)	46.57 (0.42)	31.49 (0.32)
	RTRT	49.99 (0.92)	46.57 (0.55)	28.56 (0.33)	47.86 (0.32)	50.95 (0.42)	28.20 (0.31)
	SCF	54.72 (0.53)	52.49 (0.67)	38.37 (0.63)	55.27 (0.40)	49.26 (0.42)	38.36 (0.55)
	SCRT	54.72 (0.30)	52.49 (0.46)	38.37 (0.49)	49.29 (0.37)	53.43 (0.36)	30.07 (0.36)
	Average	51.58 (0.45)	50.11 (0.45)	33.36 (0.41)	50.42 (0.32)	49.98 (0.41)	31.74 (0.38)

July	ITF	45.64 (0.53)	45.27 (0.51)	36.08 (0.50)	46.76 (0.62)	42.56 (0.50)	36.43 (0.65)
	ITRT	40.57 (0.83)	42.17 (0.36)	28.07 (0.41)	41.43 (0.91)	62.77 (0.58)	28.07 (0.43)
	RTF	41.28 (0.68)	44.75 (0.40)	32.02 (0.54)	43.56 (0.81)	42.25 (0.58)	33.68 (0.62)
	RTRT	39.58 (0.71)	41.84 (0.49)	28.14 (0.53)	39.65 (0.62)	45.27 (0.39)	27.63 (0.61)
	SCF	46.21 (0.82)	45.43 (0.55)	37.35 (0.90)	47.54 (0.93)	42.43 (0.49)	38.02 (0.66)
	SCRT	42.00 (0.73)	42.80 (0.35)	30.17 (0.36)	41.45 (0.74)	45.70 (0.59)	28.25 (0.47)
	Average	42.55 (0.72)	43.71 (0.44)	31.97 (0.54)	43.40 (0.77)	44.05 (0.52)	32.01 (0.57)
September	ITF	44.95 (0.95)	45.67 (0.60)	34.46 (0.55)	43.28 (0.74)	46.98 (0.57)	32.79 (0.61)
	ITRT	41.85 (0.64)	42.65 (0.55)	29.26 (0.47)	47.77 (0.69)	45.61 (0.70)	27.82 (0.57)

	RTF	40.97 (0.82)	44.56 (0.47)	32.13 (0.57)	41.98 (0.95)	43.32 (0.37)	31.54 (0.61)
	RTRT	39.97 (0.84)	42.47 (0.54)	29.36 (0.53)	40.66 (0.68)	45.28 (0.52)	29.84 (0.51)
	SCF	47.57 (0.85)	44.53 (0.55)	36.82 (0.52)	45.25 (0.62)	44.46 (0.40)	37.02 (0.39)
	SCRT	43.43 (0.83)	43.59 (0.44)	31.22 (0.37)	40.91 (0.53)	46.35 (0.76)	30.47 (0.44)
	Average	43.12 (0.82)	43.91 (0.52)	32.21 (0.50)	43.31 (0.73)	45.33 (0.55)	31.58 (0.52)
All Tomato Season	**ITF**	47.58 (0.58)	47.60 (0.50)	34.90 (0.29)	51.48 (0.59)	44.30 (0.36)	35.20 (0.39)
	ITRT	43.36 (0.60)	44.10 (0.45)	28.94 (0.25)	48.29 (0.56)	48.00 (0.56)	28.58 (0.28)
	RTF	47.58 (0.69)	46.28 (0.41)	31.66 (0.29)	47.57 (0.62)	43.78 (0.36)	32.62 (0.34)
	RTRT	44.03 (0.58)	42.96 (0.31)	28.56 (0.23)	42.38 (0.57)	47.13 (0.45)	28.36 (0.30)

SCF	49.77 (0.71)	47.76 (0.64)	37.57 (0.51)	50.34 (0.71)	44.90 (0.46)	37.97 (0.34)
SCRT	44.40 (0.55)	44.67 (0.41)	30.93 (0.22)	43.53 (0.60)	48.33 (0.60)	29.35 (0.27)

Table 48 Probability for the Mean L, a* and b* Values of Tomatoes. Fruits were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated measured GLM.

Source of Variation	Probability		
	L	**a***	**b***
Day	0.514	0.001	0.181
Month	<0.001	<0.001	0.092
Pre-sale Treatment	<0.001	0.106	<0.001
Post-sale Treatment	0.719	0.335	0.024
Day x Month	0.008	0.027	0.095
Day x Pre-sale Treatment	0.089	0.615	0.011
Day x Post-sale Treatment	0.005	0.050	0.004
Month x Pre-sale Treatment	0.059	<0.001	<0.001
Month x Post-sale Treatment	0.025	<0.001	<0.001
Pre-sale Treatment x Post-sale Treatment	<0.001	0.205	<0.001

Table 49 Mean Weight Loss (%) of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets represent standard error. *data not recorded.

		Weight loss (%)									
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	0.00 (0.00)	1.79 (0.23)	2.63 (0.30)	2.91 (0.57)	3.46 (1.16)	3.73 (0.23)	3.36 (0.67)	5.80 (0.08)	6.00 (0.99)	6.55 (0.50)
	ITRT	0.00 (0.00)	1.79 (0.23)	3.61 (0.28)	5.58 (0.92)	7.00 (0.22)	9.23 (0.77)	9.62 (0.86)	9.72 (0.00)	10.33 (0.00)	11.63 (2.69)
	RTF	0.00 (0.00)	3.53 (0.24)	3.14 (0.47)	3.21 (0.35)	3.84 (0.65)	5.47 (0.44)	5.47 (1.76)	5.77 (0.23)	6.08 (0.64)	7.19 (0.18)
	RTRT	0.00 (0.00)	3.53 (0.24)	5.66 (0.32)	7.37 (0.93)	7.74 (0.50)	8.34 (0.83)	8.43 (0.63)	10.81 (1.62)	10.37 (0.00)	15.66 (0.00)
	SCF	0.00 (0.00)	0.74 (0.12)	0.82 (0.16)	1.20 (0.28)	2.61 (0.19)	2.78 (0.72)	4.02 (1.76)	5.13 (1.64)	6.89 (2.00)	6.89 (2.00)
	SCRT	0.00 (0.00)	0.74 (0.12)	2.72 (0.29)	4.71 (0.31)	5.31 (0.17)	7.84 (0.61)	8.26 (1.92)	9.04 (0.37)	10.84 (2.38)	12.86 (2.91)

	Average	0.00 (0.00)	2.02 (0.10)	3.10 (0.30)	4.16 (0.55)	4.99 (0.48)	6.08 (0.60)	6.53 (1.27)	7.71 (0.66)	8.42 (1.00)	10.13 (1.38)
July	**ITF**	0.00 (0.00)	2.01 (0.11)	2.24 (0.60)	2.81 (0.48)	3.00 (0.27)	3.92 (1.01)	4.18 (0.47)	4.89 (0.11)	5.52 (1.11)	8.19 (0.28)
	ITRT	0.00 (0.00)	2.01 (0.11)	3.94 (0.38)	6.22 (0.62)	7.00 (0.31)	8.40 (0.30)	10.37 (0.45)	10.64 (0.00)	11.06 (0.71)	11.19 (3.88)
	RTF	0.00 (0.00)	3.36 (0.17)	3.14 (0.45)	4.23 (0.42)	4.34 (1.68)	5.37 (0.63)	5.75 (0.27)	6.38 (1.24)	6.73 (1.01)	*
	RTRT	0.00 (0.00)	3.36 (0.17)	5.20 (0.51)	7.37 (0.44)	7.23 (0.22)	8.98 (0.67)	9.63 (0.71)	11.98 (0.00)	13.16 (0.00)	*
	SCF	0.00 (0.00)	0.66 (0.05)	1.14 (0.28)	1.72 (0.27)	1.92 (0.12)	2.60 (0.48)	2.69 (0.45)	3.61 (0.55)	4.29 (0.58)	6.89 (0.00)
	SCRT	0.00 (0.00)	0.66 (0.05)	3.65 (5.70)	5.00 (0.43)	6.26 (0.46)	6.49 (1.11)	7.10 (0.66)	9.95 (0.59)	10.97 (0.05)	16.12 (0.76)
	Average	0.00 (0.00)	2.01 (0.05)	3.22 (0.45)	4.56 (0.44)	4.96 (0.51)	5.96 (0.70)	6.62 (0.50)	7.91 (0.42)	8.62 (0.58)	10.60 (0.82)
September	**ITF**	0.00 (0.00)	1.30 (0.11)	2.73 (0.60)	2.76 (0.48)	2.87 (0.27)	3.38 (1.01)	4.43 (1.04)	4.63 (0.75)	5.89 (0.57)	6.27 (0.56)

	ITRT	0.00 (0.00)	1.30 (0.11)	3.61 (0.38)	5.58 (0.62)	7.00 (0.31)	8.27 (0.30)	8.50 (0.49)	10.77 (0.62)	11.63 (2.69)	11.0 (0.71)
	RTF	0.00 (0.00)	2.68 (0.17)	3.39 (0.45)	4.03 (0.42)	4.48 (1.68)	4.97 (0.63)	5.19 (0.49)	5.82 (1.40)	7.19 (0.18)	7.49 (1.53)
	RTRT	0.00 (0.00)	2.68 (0.17)	4.96 (0.51)	6.73 (0.44)	7.23 (0.22)	10.17 (0.67)	11.59 (0.84)	12.08 (0.66)	14.66 (0.00)	15.16 (0.00)
	SCF	0.00 (0.00)	0.83 (0.05)	1.84 (0.28)	2.61 (0.27)	2.97 (0.12)	2.99 (0.48)	3.47 (0.26)	5.87 (0.63)	6.39 (1.60)	7.36 (0.88)
	SCRT	0.00 (0.00)	0.83 (0.05)	3.64 (0.50)	5.29 (0.43)	8.27 (0.46)	8.51 (1.11)	9.04 (0.33)	10.48 (0.45)	12.86 (1.69)	12.97 (0.95)
	Average	0.00 (0.00)	1.60 (0.05)	3.36 (0.45)	4.50 (0.44)	5.47 (0.51)	6.38 (0.70)	7.04 (0.57)	8.28 (0.75)	9.77 (1.12)	10.05 (0.77)
All Season	**ITF**	0.00 (0.00)	1.70 (0.11)	2.53 (0.29)	3.07 (0.35)	2.79 (0.60)	4.67 (0.82)	5.18 (1.17)	6.07 (1.42)	5.17 (0.57)	5.90 (0.71)
	ITRT	0.00 (0.00)	1.70 (0.11)	3.76 (0.20)	6.04 (0.39)	6.33 (0.31)	9.23 (0.82)	9.22 (0.49)	10.77 (0.86)	11.40 (1.50)	11.34 (1.34)
	RTF	0.00 (0.00)	3.18 (0.13)	3.46 (0.24)	3.86 (0.24)	3.41 (0.28)	4.99 (0.46)	5.00 (0.62)	6.03 (0.92)	5.29 (0.67)	4.97 (0.91)

RTRT	0.00 (0.00)	3.18 (0.13)	5.27 (0.25)	7.47 (0.42)	7.49 (0.27)	10.89 (1.02)	10.04 (0.57)	11.21 (1.04)	13.06 (1.53)	14.41 (1.25)
SCF	0.00 (0.00)	0.74 (0.05)	1.27 (0.15)	1.84 (0.26)	1.43 (0.22)	3.29 (0.59)	2.79 (0.68)	3.73 (0.66)	3.62 (1.39)	4.41 (1.83)
SCRT	0.00 (0.00)	0.74 (0.05)	5.17 (1.91)	6.83 (1.85)	7.41 (0.83)	10.91 (3.66)	12.04 (3.77)	12.36 (3.39)	12.25 (0.74)	13.25 (0.97)

Table 50 Probability for the Mean Weight Loss (%) of Tomatoes. Fruit were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Day 7 data was analysed by GLM, and day 11 data onwards was analsyed by repeated measures GLM.

Weight Loss (%)	
Day 7	
Source of Variation	**Probability**
Month	0.003
Treatment	<0.001
Month x Treatment	0.016
Day 11 onwards	
Source of Variation	**Probability**
Day	<0.001
Month	0.006
Pre-sale Treatment	<0.001
Post-sale Treatment	0.003
Day x Month	0.018
Day x Pre-sale Treatment	0.113
Day x Post-sale Treatment	<0.001
Month x Pre-sale Treatment	0.072
Month x Post-sale Treatment	0.552
Pre-sale Treatment x Post-sale Treatment	0.034

Table 51 Mean Deformation (N/mm) of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets represent standard error. *data not recorded.

		Firmness Deformation Modulus (N/mm)									
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	5.72 (0.67)	4.26 (0.46)	4.28 (0.67)	3.73 (0.48)	3.98 (0.52)	3.37 (0.34)	4.04 (0.87)	2.49 (0.27)	2.32 (0.22)	2.22 (0.23)
	ITRT	5.72 (0.67)	4.26 (0.46)	3.35 (0.42)	2.83 (0.29)	2.85 (0.41)	2.48 (0.42)	2.65 (0.45)	2.24 (0.26)	2.40 (0.26)	2.27 (0.32)
	RTF	5.74 (0.35)	3.28 (0.38)	2.75 (0.26)	2.78 (0.30)	3.11 (0.42)	3.03 (0.57)	3.73 (0.59)	2.29 (0.21)	2.15 (0.26)	1.81 (0.33)
	RTRT	5.74 (0.35)	3.28 (0.38)	2.93 (0.27)	2.79 (0.34)	2.65 (0.48)	2.26 (0.40)	3.26 (0.63)	2.53 (0.31)	2.53 (0.30)	2.18 (0.30)
	SCF	4.80 (0.50)	4.64 (0.72)	4.85 (0.57)	4.40 (0.48)	3.79 (0.68)	4.41 (0.62)	4.26 (1.08)	3.49 (0.44)	2.86 (0.28)	2.75 (0.39)
	SCRT	4.80 (0.50)	4.64 (0.72)	3.32 (0.33)	3.01 (0.37)	2.90 (0.52)	2.76 (0.48)	2.18 (0.31)	2.32 (0.28)	2.40 (0.32)	2.38 (0.44)

	Average	5.42 (0.51)	4.06 (0.52)	3.58 (0.42)	3.26 (0.38)	3.21 (0.51)	3.05 (0.47)	3.35 (0.66)	2.56 (0.29)	2.44 (0.27)	2.27 (0.34)
July	**ITF**	6.36 (0.83)	4.73 (0.47)	4.88 (0.54)	4.71 (0.60)	3.66 (0.97)	4.41 (0.78)	4.46 (1.32)	4.07 (0.74)	4.03 (0.64)	3.95 (0.42)
	ITRT	6.36 (0.83)	4.73 (0.47)	3.71 (0.48)	3.27 (0.38)	3.08 (0.48)	3.56 (0.66)	4.04 (1.11)	2.74 (0.38)	3.11 (0.68)	2.73 (0.37)
	RTF	7.05 (0.94)	4.01 (0.61)	3.64 (0.51)	3.42 (0.41)	4.22 (1.15)	3.61 (0.64)	3.64 (0.79)	2.81 (0.39)	2.34 (0.30)	2.14 (0.22)
	RTRT	7.05 (0.94)	4.01 (0.61)	3.59 (0.44)	3.28 (0.48)	3.69 (0.85)	3.01 (0.45)	2.93 (0.82)	3.10 (0.48)	2.38 (0.41)	2.34 (0.25)
	SCF	6.46 (1.05)	5.69 (0.78)	5.25 (0.61)	4.12 (0.53)	5.32 (1.28)	5.17 (0.73)	5.32 (1.18)	4.55 (0.73)	3.78 (0.73)	3.80 (0.49)
	SCRT	6.46 (1.05)	5.69 (0.78)	3.64 (0.44)	4.10 (1.00)	3.60 (0.95)	2.91 (0.44)	3.31 (0.76)	2.72 (0.48)	2.61 (0.38)	2.30 (0.24)
	Average	6.62 (0.94)	4.81 (0.62)	4.12 (0.50)	3.82 (0.57)	3.93 (0.95)	3.78 (0.62)	3.95 (1.00)	3.33 (0.54)	3.04 (0.52)	2.88 (0.33)
September	**ITF**	4.91 (0.72)	3.22 (0.35)	3.69 (0.34)	3.69 (0.35)	3.03 (0.37)	2.92 (0.32)	2.81 (0.33)	3.09 (0.27)	2.69 (0.25)	*

	ITRT	4.91 (0.72)	3.22 (0.35)	3.18 (0.30)	2.66 (0.21)	2.95 (0.38)	2.65 (0.30)	2.47 (0.26)	1.97 (0.20)	2.64 (0.28)	1.63 (0.15)
	RTF	5.03 (0.83)	2.80 (0.25)	2.93 (0.32)	2.53 (0.21)	2.33 (0.43)	2.39 (0.29)	2.18 (0.22)	2.38 (0.29)	2.21 (0.20)	*
	RTRT	5.03 (0.83)	2.80 (0.25)	2.58 (0.20)	2.51 (0.24)	2.33 (0.33)	2.57 (0.39)	2.28 (0.30)	1.96 (0.18)	2.48 (0.24)	1.86 (0.11)
	SCF	4.88 (0.88)	4.62 (0.46)	4.03 (0.44)	3.06 (0.31)	3.34 (0.63)	3.56 (0.39)	3.23 (0.24)	3.75 (0.50)	3.17 (0.31)	*
	SCRT	4.88 (0.88)	4.62 (0.46)	3.28 (0.31)	2.87 (0.28)	2.71 (0.31)	2.49 (0.25)	2.32 (0.20)	2.31 (0.25)	2.47 (0.24)	1.77 (0.12)
	Average	4.94 (0.81)	3.55 (0.35)	3.28 (0.32)	2.89 (0.27)	2.78 (0.36)	2.76 (0.32)	2.55 (0.26)	2.57 (0.28)	2.61 (0.25)	1.75 (0.13)
All Season	**ITF**	5.81 (0.44)	4.07 (0.26)	4.29 (0.31)	3.94 (0.29)	3.93 (0.52)	3.57 (0.32)	3.77 (0.50)	3.03 (0.26)	2.89 (0.22)	3.37 (0.35)
	ITRT	5.81 (0.44)	4.07 (0.26)	3.41 (0.23)	3.01 (0.20)	2.94 (0.23)	2.90 (0.29)	3.11 (0.42)	2.30 (0.17)	2.63 (0.20)	2.34 (0.22)
	RTF	6.10 (0.46)	3.37 (0.26)	3.11 (0.22)	3.02 (0.22)	3.43 (0.43)	3.01 (0.31)	3.25 (0.35)	2.44 (0.16)	2.21 (0.14)	1.95 (0.19)

RTRT	6.10 (0.46)	3.37 (0.26)	3.03 (0.19)	2.88 (0.21)	2.89 (0.35)	2.61 (0.24)	2.92 (0.35)	2.53 (0.21)	2.48 (0.17)	2.12 (0.14)
SCF	5.51 (0.50)	4.98 (0.39)	4.7 (0.32)	3.97 (0.29)	4.15 (0.55)	4.38 (0.36)	4.38 (0.54)	3.82 (0.31)	3.17 (0.22)	3.45 (0.37)
SCRT	5.51 (0.50)	4.98 (0.39)	3.42 (0.21)	3.33 (0.36)	3.07 (0.36)	2.72 (0.22)	2.66 (0.29)	2.42 (0.19)	2.47 (0.17)	2.10 (0.14)

Table 52 Probability for the Mean Deformation (N/mm) and Penetration (N) Values of Tomatoes at Day 0 and 7. Fruits were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C). Data was anlaysed by GLM.

		Deformation (N/mm)	Penetration (N)
Day	**Source of Variation**	**Probability**	
0	**Month**	0.273	0.999
	Treatment	0.329	0.099
	Month x Treatment	0.947	0.999
7	**Month**	0.015	<0.001
	Treatment	0.001	<0.001
	Month x Treatment	0.918	0.003

Table 53 Probability for Mean Deformation Values of Tomato from Day 7. Fruits were stored either for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated measures GLM.

Source of Variation	Probability
Day	<0.001
Month	0.042
Pre-sale Treatment	0.013
Post-sale Treatment	0.001
Day x Month	0.976
Day x Pre-sale Treatment	0.928
Day x Post-sale Treatment	0.836
Month x Pre-sale Treatment	0.479
Month x Post-sale Treatment	0.235
Pre-sale Treatment x Post-sale Treatment	<0.001

Table 54 Mean Penetration Values (N) of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets represent standard error. *data not recorded

		Firmness Penetration (N)									
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	11.21 (0.58)	8.95 (0.41)	8.37 (0.47)	8.85 (0.39)	7.40 (0.85)	5.86 (0.71)	4.98 (1.15)	2.66 (0.63)	3.17 (0.79)	4.55 (1.12)
	ITRT	11.21 (0.58)	8.95 (0.41)	6.71 (0.56)	5.29 (0.33)	6.21 (0.34)	5.81 (0.47)	5.76 (0.32)	5.02 (0.37)	7.08 (0.77)	4.86 (0.33)
	RTF	14.01 (0.99)	6.88 (0.33)	7.31 (0.59)	7.07 (0.40)	6.35 (0.38)	5.18 (0.43)	5.19 (0.96)	2.73 (0.70)	3.00 (0.66)	2.17 (0.61)
	RTRT	14.01 (0.99)	6.88 (0.33)	5.12 (0.27)	5.71 (0.43)	5.87 (0.70)	5.05 (0.47)	5.49 (0.18)	5.49 (0.64)	5.47 (0.85)	5.95 (0.34)
	SCF	12.05 (0.70)	9.73 (0.52)	8.49 (0.39)	9.83 (0.53)	7.62 (0.82)	9.14 (0.58)	7.16 (0.78)	6.99 (1.19)	5.60 (0.83)	5.75 (1.20)
	SCRT	12.05 (0.70)	9.73 (0.52)	6.41 (0.58)	6.35 (0.57)	6.59 (0.58)	6.12 (0.43)	5.61 (0.89)	3.66 (0.57)	6.13 (0.49)	5.15 (0.52)

July	**ITF**	10.94 (0.42)	8.74 (0.56)	9.12 (0.65)	8.59 (0.34)	*	7.44 (0.73)	7.38 (0.65)	7.27 (1.19)	2.61 (1.28)	4.45 (0.77)
	ITRT	10.94 (0.42)	8.74 (0.56)	7.02 (0.56)	6.65 (0.45)	6.38 (0.24)	7.24 (0.52)	8.18 (0.32)	5.90 (0.41)	5.04 (1.95)	6.15 (0.59)
	RTF	11.96 (0.48)	7.26 (0.38)	7.39 (0.49)	7.62 (0.43)	*	6.62 (0.74)	7.43 (0.38)	4.42 (0.21)	3.83 (0.94)	3.97 (0.00)
	RTRT	11.96 (0.48)	7.26 (0.38)	6.88 (0.48)	7.57 (0.46)	4.79 (0.48)	6.80 (0.50)	6.57 (0.48)	5.47 (0.50)	6.47 (0.25)	6.88 (0.61)
	SCF	10.94 (0.36)	9.08 (0.53)	8.64 (0.58)	7.04 (0.58)	*	8.54 (0.87)	7.39 (0.67)	7.27 (0.21)	6.21 (0.60)	7.56 (1.10)
	SCRT	10.94 (0.36)	9.08 (0.53)	7.26 (0.42)	6.97 (0.29)	5.07 (0.35)	8.01 (0.59)	7.21 (0.37)	5.13 (0.60)	6.72 (0.47)	7.18 (0.38)
September	**ITF**	11.07 (0.17)	9.00 (0.17)	8.77 (0.58)	8.72 (0.30)	7.40 (0.85)	6.76 (0.62)	6.54 (0.36)	4.89 (0.97)	4.36 (1.16)	*
	ITRT	11.07 (0.17)	9.00 (0.17)	6.87 (0.50)	5.97 (0.33)	4.50 (0.27)	5.73 (0.44)	4.11 (0.16)	5.90 (0.43)	6.96 (0.53)	7.12 (0.66)
	RTF	11.50 (0.18)	7.07 (0.18)	7.35 (0.24)	7.34 (0.30)	6.35 (0.38)	6.21 (0.50)	5.96 (0.31)	3.92 (0.29)	2.73 (0.57)	*

	RTRT	11.50 (0.18)	7.07 (0.18)	6.52 (0.16)	6.64 (0.25)	4.52 (0.35)	4.37 (0.44)	6.38 (0.42)	5.47 (0.50)	5.45 (0.84)	6.04 (0.45)
	SCF	11.50 (0.20)	9.40 (0.34)	8.56 (0.39)	8.44 (0.43)	7.33 (0.47)	8.84 (0.51)	7.82 (0.46)	7.26 (0.70)	5.61 (0.52)	*
	SCRT	11.50 (0.20)	9.40 (0.34)	6.84 (0.37)	6.66 (0.27)	5.08 (0.19)	6.64 (0.42)	4.36 (0.27)	4.76 (0.46)	5.86 (0.36)	6.24 (0.25)
All Season	**ITF**	8.47 (0.67)	7.27 (0.48)	7.03 (0.49)	7.28 (0.39)	6.24 (0.57)	5.66 (0.49)	5.96 (0.43)	4.71 (0.64)	4.45 (0.74)	4.55 (0.65)
	ITRT	8.47 (0.67)	7.27 (0.48)	5.89 (0.35)	5.46 (0.24)	6.38 (0.17)	5.57 (0.31)	6.39 (0.29)	6.78 (0.33)	5.85 (0.51)	6.02 (0.53)
	RTF	9.68 (0.89)	5.85 (0.34)	6.11 (0.40)	6.54 (0.29)	4.94 (0.48)	5.00 (0.39)	6.60 (0.37)	3.41 (0.28)	2.76 (0.42)	3.13 (0.55)
	RTRT	9.68 (0.89)	5.85 (0.34)	5.71 (0.26)	6.11 (0.28)	4.79 (0.34)	5.35 (0.39)	5.96 (0.23)	5.76 (0.31)	5.85 (0.45)	6.33 (0.27)
	SCF	9.07 (0.64)	7.62 (0.51)	7.17 (0.41)	8.32 (0.37)	6.57 (0.66)	6.97 (0.63)	6.94 (0.32)	6.71 (0.45)	6.07 (0.45)	6.72 (0.55)
	SCRT	9.07 (0.64)	7.62 (0.51)	6.11 (0.31)	6.58 (0.26)	5.58 (0.30)	5.88 (0.35)	6.19 (0.36)	5.42 (0.33)	5.98 (0.39)	6.27 (0.26)

Table 55 Probability for the Mean Penetration Values of Tomatoes. Fruits were stored for 7 days at IT (15°C), RT (23°C) or SC (average 12°C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated measures GLM.

Source of Variation	Probability
Day	<0.001
Month	0.280
Pre-sale Treatment	0.301
Post-sale Treatment	<0.001
Day x Month	<0.001
Day x Pre-sale Treatment	0.151
Day x Post-sale Treatment	<0.001
Month x Pre-sale Treatment	0.037
Month x Post-sale Treatment	0.130
Pre-sale Treatment x Post-sale Treatment	<0.001

Table 56 Mean All-Trans Lycopene Content of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT

Month	Treatment	All-trans Lycopene mg/100 FW									
		Day									
		0	7	11	15	20	23	26	30	35	40
May	ITF	3.72 (0.65)	5.30 (1.08)	7.35 (2.07)	9.35 (2.69)	8.79 (0.21)	7.96	15.26 (2.53)	12.05 (1.47)	10.83 (0.42)	17.06 (2.51)
	ITRT	3.72 (0.65)	5.30 (1.08)	8.12 (2.00)	14.50 (4.76)	10.60 (2.62)	11.93	21.49 (4.55)	14.38 (3.16)	19.58 (2.02)	21.59 (6.35)
	RTF	3.62 (0.81)	8.89 (1.90)	9.88 (2.89)	9.12 (1.75)	16.74 (3.67)	9.09	10.40 (3.06)	9.37 (1.61)	15.71 (1.50)	14.83 (2.73)
	RTRT	3.62 (0.81)	8.89 (1.90)	9.85 (1.81)	18.86 (3.39)	14.79 (1.54)	22.71 (5.97)	17.25 (0.42)	13.56 (2.17)	14.67 (1.78)	19.11 (2.66)
	SCF	5.14 (0.71)	5.12 (0.46)	2.65 (0.56)	9.98 (1.18)	6.81 (0.11)	5.94	6.70 (1.75)	5.49 (1.82)	12.18 (0.45)	12.14 (1.34)
	SCRT	5.14 (0.71)	5.12 (0.46)	12.12 (3.31)	11.21 (2.85)	10.03 (0.70)	11.05	15.03 (2.23)	17.21 (2.78)	17.39 (0.16)	11.72 (2.18)

July	**ITF**	5.52 (1.19)	4.10 (0.43)	8.76 (2.12)	12.26 (1.86)	10.29 (0.01)	8.33 (0.95)	6.66 (1.06)	14.28 (2.62)	15.27 (2.65)	13.20 (2.38)
	ITRT	5.52 (1.19)	4.10 (0.43)	12.76 (3.41)	10.98 (0.23)	9.67 (0.95)	9.17 (0.60)	12.10 (2.40)	14.52 (3.28)	19.57 (3.17)	13.43 (3.98)
	RTF	6.00 (0.66)	6.89 (0.56)	9.96 (2.66)	13.22 (2.68)	7.64 (5.40)	9.88 (1.55)	9.87 (5.18)	13.60 (1.71)	11.60 (0.95)	16.00 (2.55)
	RTRT	6.00 (0.66)	6.89 (0.56)	8.46 (0.39)	18.53 (2.95)	14.04 (0.00)	17.86 (0.00)	11.59 (2.86)	21.34 (4.09)	18.04 (1.71)	21.05 (2.55)
	SCF	4.99 (0.89)	2.30 (0.46)	9.86 (0.87)	7.69 (1.54)	8.86 (2.67)	6.26 (2.03)	7.64 (2.09)	11.45 (3.86)	15.58 (0.81)	12.18 (0.45)
	SCRT	4.99 (0.89)	2.30 (0.46)	11.08 (2.29)	11.70 (1.06)	15.22 (5.93)	11.90 (0.05)	13.70 (1.31)	17.51 (2.31)	17.19 (1.74)	17.02 (0.38)
September	**ITF**	5.45 (0.86)	6.45 (1.24)	6.24 (0.58)	5.03 (0.30)	10.09 (1.23)	7.90	11.81 (1.41)	10.08 (1.77)	14.82 (1.68)	14.95 (2.90)
	ITRT	5.45 (0.86)	6.45 (1.24)	9.79 (2.95)	9.98 (0.62)	17.32 (1.00)	14.11	13.63 (5.81)	14.52 (4.09)	15.21 (1.77)	17.14 (0.16)
	RTF	3.95 (1.71)	11.87 (2.98)	7.21 (0.55)	6.57 (0.94)	11.99 (4.52)	9.56	11.18 (4.93)	13.60 (2.36)	12.80 (0.70)	18.94 (5.56)

	RTRT	3.95 (1.71)	11.87 (2.98)	15.27 (4.52)	9.76 (1.08)	12.56 (2.54)	13.01 (5.13)	18.17 (2.86)	21.34 (0.78)	21.48 (0.28)	21.20
	SCF	4.58 (1.83)	7.41 (1.72)	8.71 (1.89)	5.89 (1.60)	12.13	16.85	12.92 (1.75)	10.91 (3.28)	12.14 (1.34)	15.31 (2.06)
	SCRT	4.58 (1.83)	7.41 (1.72)	8.48 (0.61)	11.46 (2.42)	9.01 (0.51)	10.98	15.24 (2.25)	12.30 (2.86)	15.32 (0.84)	14.96 (0.35)
All Season	**ITF**	4.27 (0.55)	6.17 (0.58)	7.45 (0.98)	8.52 (1.27)	9.87 (0.36)	8.13 (0.41)	11.30 (1.66)	11.93 (1.16)	13.81 (1.16)	14.28 (1.41)
	ITRT	4.27 (0.55)	6.17 (0.58)	10.18 (1.60)	11.82 (1.51)	11.81 (1.89)	11.74 (1.09)	15.74 (2.67)	15.66 (1.88)	18.48 (1.46)	18.63 (2.72)
	RTF	4.18 (0.62)	8.25 (1.60)	9.12 (1.35)	9.82 (1.29)	11.00 (3.09)	12.40 (4.15)	10.48 (2.18)	12.24 (1.14)	13.44 (0.91)	16.93 (2.40)
	RTRT	4.18 (0.62)	8.25 (1.60)	12.06 (1.67)	15.72 (1.02)	13.60 (3.27)	16.61 (5.28)	15.67 (1.53)	15.75 (3.60)	18.06 (1.40)	20.30 (1.78)
	SCF	4.97 (0.61)	4.95 (0.92)	6.95 (1.23)	8.00 (0.88)	10.36 (1.13)	8.32 (3.33)	8.94 (1.26)	9.41 (1.83)	13.63 (0.82)	13.89 (1.07)
	SCRT	4.97 (0.61)	4.95 (0.92)	10.68 (1.28)	11.46 (1.15)	12.37 (2.94)	11.31 (0.29)	14.72 (1.05)	15.67 (1.56)	16.71 (0.77)	15.06 (0.85)

Table 57 Probability for the Mean All-trans Lycopene, 9-cis lycopene, β-carotene and Lutein Contents of Tomatoes at Day 0 and Day 7. Fruits were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C). Data was analysed by GLM.

Day	Source of Variation	All-trans Lycopene mg/100g FW	9-cis Lycopene mg/100g FW	β-carotene mg/100g FW	Lutein mg/100g FW
		Probability			
0	Month	0.041	0.003	0.005	0.535
	Treatment	0.629	0.670	0.286	0.322
	Month x Treatment	0.655	0.130	0.202	0.580
7	Month	0.020	0.185	0.071	0.165
	Treatment	0.009	0.030	0.415	0.890
	Month x Treatment	0.905	0.049	0.112	0.828

Table 58 Probability for Mean All-trans Lycopene Values of Tomatoes. Fruits were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated measured GLM.

Source of Variation	Probability
Day	<0.001
Month	0.076
Pre-sale Treatment	0.123
Post-sale Treatment	<0.001
Day x Month	0.186
Day x Pre-sale Treatment	0.472
Day x Post-sale Treatment	0.096
Month x Pre-sale Treatment	0.361
Month x Post-sale Treatment	0.488
Pre-sale Treatment x Post-sale Treatment	0.773

Table 59 Mean 9-cis Lycopene Content of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets represent standard error.

		9-cis Lycopene mg/100g FW									
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	0.38 (0.10)	0.51 (0.05)	0.81 (0.22)	0.99 (0.29)	0.80	1.08	1.68 (0.33)	1.55 (0.14)	1.53 (0.03)	2.03 (0.18)
	ITRT	0.38 (0.10)	0.51 (0.05)	0.72 (0.18)	1.37 (0.55)	1.22 (0.12)	1.20	1.95 (0.26)	1.44 (0.46)	1.89 (0.07)	2.20 (0.76)
	RTF	0.47 (0.22)	0.86 (0.17)	1.05 (0.28)	0.98 (0.11)	1.52 (0.62)	1.58	1.24 (0.25)	1.22 (0.11)	1.23 (0.20)	1.89 (0.30)
	RTRT	0.47 (0.22)	0.86 (0.17)	1.44 (0.21)	1.53 (0.24)	1.76 (0.62)	1.63 (0.56)	1.53 (0.23)	1.22 (0.33)	1.77 (0.17)	1.77 (0.13)
	SCF	0.44 (0.11)	0.41 (0.08)	0.21 (0.03)	1.19 (0.11)	1.88	0.44	0.84 (0.19)	0.74 (0.26)	1.67 (0.04)	1.46 (0.21)
	SCRT	0.44 (0.11)	0.41 (0.08)	1.17 (0.24)	1.03 (0.28)	1.13 (0.08)	1.0 2	1.43 (0.25)	2.09 (0.16)	1.58 (0.46)	1.46 (0.17)

July	**ITF**	0.75 (0.10)	0.83 (0.11)	0.67 (0.24)	1.25 (0.15)	0.96 (0.06)	1.24 (0.12)	1.04 (0.24)	1.64 (0.35)	1.51 (0.23)	1.52 (0.03)
	ITRT	0.75 (0.10)	0.83 (0.11)	1.12 (0.32)	1.15 (0.08)	1.34 (0.09)	1.19 (0.07)	1.44 (0.17)	1.50 (0.08)	1.75 (0.15)	1.61 (0.42)
	RTF	0.12 (0.04)	0.42 (0.14)	0.97 (0.25)	1.05 (0.21)	1.62 (0.45)	1.15 (0.27)	1.20 (0.54)	1.46 (0.26)	1.23 (0.15)	2.06 (0.26)
	RTRT	0.12 (0.04)	0.42 (0.14)	2.04 (0.08)	1.73 (0.26)	1.20 (1.53)	1.89 (1.26)	1.11 (0.01)	2.04 (0.53)	1.75 (0.21)	2.58 (0.62)
	SCF	0.63 (0.04)	0.26 (0.07)	1.02 (0.07)	1.09 (0.17)	0.84 (0.23)	0.75 (0.38)	1.00 (0.17)	1.57 (0.13)	1.57 (0.31)	1.67 (0.04)
	SCRT	0.63 (0.04)	0.26 (0.07)	1.01 (0.28)	1.22 (0.11)	1.40 (0.30)	1.34 (0.11)	1.32 (0.31)	1.68 (0.09)	1.59 (0.04)	2.04 (0.05)
September	**ITF**	0.50 (0.05)	0.59 (0.15)	0.96 (0.10)	0.67 (0.07)	0.92	1.10	1.26 (0.29)	1.10 (0.30)	1.89 (0.15)	1.92 (0.25)
	ITRT	0.50 (0.05)	0.59 (0.15)	1.02 (0.24)	0.94 (0.12)	2.16 (0.10)	1.02	1.65 (0.77)	1.84 (0.08)	1.38 (0.66)	1.38 (0.10)
	RTF	0.41 (0.05)	0.77 (0.23)	0.97 (0.06)	0.98 (0.14)	1.42 (0.17)	0.66	0.93 (0.35)	1.63 (0.37)	1.57 (0.03)	2.12 (0.60)

	RTRT	0.41 (0.05)	0.77 (0.23)	1.20 (0.49)	1.20 (0.09)	0.99 (0.10)	0.91 (0.15)	1.49 (0.07)	1.04 (0.29)	2.00 (0.32)	2.33
	SCF	0.48 (0.14)	0.59 (0.13)	0.93 (0.16)	0.78 (0.14)	0.95	1.92	1.41 (0.04)	1.01 (0.32)	1.46 (0.21)	2.20 (0.04)
	SCRT	0.48 (0.14)	0.59 (0.13)	1.14 (0.08)	1.28 (0.06)	1.27 (0.38)	1.32	1.41 (0.25)	0.84 (0.22)	1.62 (0.13)	1.73 (0.11)
All Season	**ITF**	0.38 (0.04)	0.62 (0.06)	0.81 (0.11)	1.07 (0.16)	0.91 (0.05)	1.16 (0.07)	1.33 (0.17)	1.40 (0.16)	1.68 (0.11)	1.83 (0.12)
	ITRT	0.38 (0.04)	0.62 (0.06)	0.96 (0.14)	1.15 (0.17)	1.52 (0.20)	1.12 (0.05)	1.64 (0.26)	1.58 (0.18)	1.71 (0.16)	1.85 (0.24)
	RTF	0.47 (0.08)	0.94 (0.32)	1.00 (0.13)	1.01 (0.13)	1.08 (0.18)	1.39 (0.46)	1.14 (0.19)	1.44 (0.14)	1.58 (0.14)	2.04 (0.28)
	RTRT	0.47 (0.08)	0.94 (0.32)	1.54 (0.21)	1.49 (0.10)	1.20 (0.49)	1.79 (0.60)	1.37 (0.99)	1.48 (0.27)	1.84 (0.12)	2.22 (0.27)
	SCF	0.62 (0.04)	0.42 (0.06)	0.73 (0.12)	1.03 (0.09)	1.26 (0.21)	0.97 (0.32)	1.07 (0.99)	1.10 (0.17)	1.56 (0.13)	1.77 (0.14)
	SCRT	0.62 (0.04)	0.42 (0.06)	1.11 (0.14)	1.17 (0.11)	1.30 (0.14)	1.06 (0.24)	1.39 (0.14)	1.52 (0.19)	1.74 (0.10)	1.74 (0.10)

Table 60 Probability for Mean 9-cis Lycopene Values of Tomatoes. Fruits were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated measures GLM.

Source of Variation	Probability
Day	<0.001
Month	0.171
Pre-sale Treatment	0.062
Post-sale Treatment	<0.001
Day x Month	0.170
Day x Pre-sale Treatment	0.207
Day x Post-sale Treatment	0.025
Month x Pre-sale Treatment	0.649
Month x Post-sale Treatment	0.667
Pre-sale Treatment x Post-sale Treatment	0.435

Table 61 Mean β-carotene Content of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets represent standard error.

		β-carotene mg/100g FW									
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	1.19 (0.06)	2.25 (0.57)	2.12 (0.52)	3.43 (0.86)	2.61 (0.00)	2.58	2.97 (0.05)	3.20 (0.31)	3.53 (0.40)	5.65 (0.10)
	ITRT	1.19 (0.06)	2.25 (0.57)	1.78 (0.52)	2.14 (0.62)	2.18 (0.56)	2.08	3.13 (0.58)	2.39 (0.53)	2.96 (0.76)	5.45 (0.47)
	RTF	0.83 (0.05)	3.09 (0.78)	3.35 (0.99)	2.23 (0.57)	4.86 (0.36)	2.74	3.75 (0.93)	3.41 (1.15)	3.41 (0.46)	4.80 (1.52)
	RTRT	0.83 (0.05)	3.09 (0.78)	3.57 (0.85)	3.86 (0.36)	4.45 (0.30)	1.73 (1.34)	3.59 (0.54)	1.82 (0.64)	1.82 (0.08)	4.28 (1.64)
	SCF	2.03 (0.09)	2.04 (0.66)	2.08 (1.25)	3.87 (0.37)	3.84 (0.00)	2.11	2.72 (0.37)	2.15 (0.46)	3.68 (1.07)	4.95 (1.76)
	SCRT	2.03 (0.09)	2.04 (0.66)	3.49 (0.76)	2.55 (0.69)	2.30 (0.04)	2.92	4.27 (1.06)	4.83 (0.50)	4.83 (0.03)	2.70 (0.33)

July	**ITF**	2.55 (0.70)	3.07 (0.45)	1.80 (0.44)	3.25 (0.66)	2.94 (0.54)	3.35 (0.56)	3.26 (0.39)	4.86 (1.06)	3.83 (0.56)	3.53 (0.40)
	ITRT	2.55 (0.70)	3.07 (0.45)	2.28 (0.34)	1.63 (0.26)	2.15 (0.29)	2.09 (0.21)	3.25 (0.69)	3.59 (0.61)	3.71 (0.62)	2.34 (0.13)
	RTF	3.50 (0.20)	1.50 (0.60)	2.00 (0.51)	2.99 (0.79)	2.71 (1.95)	3.20 (0.17)	3.54 (1.83)	3.12 (0.40)	3.56 (0.77)	4.35 (0.69)
	RTRT	3.50 (0.20)	1.50 (0.60)	2.93 (0.17)	2.43 (0.36)	2.78 (0.00)	3.31 (0.00)	2.58 (0.49)	4.41 (0.87)	2.94 (0.08)	4.33 (1.48)
	SCF	2.22 (0.48)	1.04 (0.30)	2.50 (0.19)	2.46 (0.19)	3.29 (0.83)	2.43 (0.04)	3.30 (0.85)	5.76 (0.21)	4.86 (0.87)	3.68 (0.50)
	SCRT	2.22 (0.48)	1.04 (0.30)	2.78 (0.89)	2.00 (0.16)	3.32 (0.00)	2.25 (0.19)	3.23 (0.60)	4.49 (0.62)	3.80 (0.34)	4.81 (1.47)
September	**ITF**	2.66 (0.28)	2.25 (0.66)	2.40 (0.26)	1.81 (0.17)	2.93 (0.00)	2.30	4.20 (0.32)	3.39 (0.86)	6.05 (0.48)	6.20 (0.79)
	ITRT	2.66 (0.28)	2.25 (0.66)	2.61 (0.70)	4.04 (0.92)	5.24 (0.61)	3.12	3.28 (1.60)	5.03 (0.72)	2.71 (0.26)	4.72 (1.30)
	RTF	1.80 (1.13)	3.72 (1.07)	2.92 (0.15)	2.72 (0.47)	3.96 (0.36)	2.13	3.26 (1.34)	4.94 (1.01)	3.79 (0.51)	5.52 (0.93)

	RTRT	1.80 (1.13)	3.72 (1.07)	3.65 (1.35)	2.29 (0.18)	2.20 (0.59)	2.24 (0.83)	2.69 (0.07)	2.36 (0.23)	6.54 (0.62)	7.16
	SCF	2.60 (0.69)	2.81 (0.69)	2.74 (0.42)	2.29 (0.76)	3.98	3.71	4.88 (0.74)	3.71 (1.05)	4.95 (1.76)	6.60 (1.26)
	SCRT	2.60 (0.69)	2.81 (0.69)	2.86 (0.18)	3.14 (0.21)	2.92 (1.51)	3.88	3.20 (0.570	2.112 (0.63)	2.70 (0.33)	3.93 (0.00)
All Season	**ITF**	1.97 (0.42)	2.45 (0.34)	2.01 (0.25)	2.72 (0.40)	2.85 (0.24)	2.90 (0.35)	3.87 (0.42)	3.77 (0.51)	4.69 (0.54)	5.12 (0.57)
	ITRT	1.97 (0.42)	2.45 (0.34)	2.26 (0.32)	2.60 (0.55)	2.93 (0.78)	2.47 (0.30)	3.61 (0.64)	3.54 (0.57)	3.21 (0.32)	3.77 (0.72)
	RTF	2.15 (0.59)	2.75 (0.52)	2.75 (0.39)	2.64 (0.36)	3.56 (0.95)	2.77 (0.25)	3.54 (0.68)	4.14 (0.56)	3.83 (0.32)	4.98 (0.55)
	RTRT	2.15 (0.59)	2.75 (0.52)	3.42 (0.49)	2.86 (0.59)	2.78 (0.32)	2.38 (0.41)	2.96 (0.28)	2.93 (0.57)	4.08 (0.79)	4.87 (0.90)
	SCF	2.15 (0.33)	1.93 (0.38)	2.06 (0.30)	3.36 (0.52)	3.93 (0.36)	3.55 (1.23)	3.6 (0.48)	3.70 (0.65)	4.55 (0.56)	5.41 (0.99)
	SCRT	2.15 (0.33)	1.93 (0.38)	3.06 (0.40)	2.51 (0.49)	2.97 (0.54)	3.01 (0.50)	3.60 (0.40)	3.69 (0.50)	3.15 (0.27)	3.41 (0.69)

Table 62 Probability for Mean β-carotene Values of Tomatoes. Fruits were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 23˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated measures GLM.

Source of Variation	Probability
Day	<0.001
Month	0.719
Pre-sale Treatment	0.156
Post-sale Treatment	0.009
Day x Month	0.692
Day x Pre-sale Treatment	0.234
Day x Post-sale Treatment	0.002
Month x Pre-sale Treatment	0.581
Month x Post-sale Treatment	0.572
Pre-sale Treatment x Post-sale Treatment	0.902

Table 63 Mean Lutein Content of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets represent standard error.

		Lutein mg/100g FW									
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	0.43 (0.12)	0.28 (0.15)	0.33 (0.00)	0.71 (0.10)	0.51 (0.00)	0.27	0.51 (0.00)	0.48 (0.00)	0.48 (0.27)	0.52 (0.16)
	ITRT	0.43 (0.12)	0.28 (0.15)	0.31 (0.06)	0.40 (0.11)	0.45 (0.35)	0.49	0.42 (0.00)	0.28 (0.22)	0.64 (0.15)	0.46 (0.23)
	RTF	0.21 (0.00)	0.33 (0.17)	0.29 (0.04)	0.53 (0.11)	0.21 (0.00)	0.42	0.38 (0.18)	0.38 (0.03)	0.38 (0.00)	0.25 (0.00)
	RTRT	0.21 (0.00)	0.33 (0.17)	0.38 (0.00)	0.41 (0.09)	0.48 (0.00)	0.40 (0.00)	0.38 (0.00)	0.17 (0.03)	0.92 (0.08)	0.70 (0.02)
	SCF	0.82 (0.08)	0.39 (0.22)	0.45 (0.09)	0.19 (0.05)	0.45 (0.00)	0.30	0.34 (0.06)	0.31 (0.08)	0.51 (0.27)	0.29 (0.00)
	SCRT	0.82 (0.08)	0.39 (0.22)	0.49 (0.10)	0.37 (0.05)	0.57 (0.20)	0.47	0.51 (0.15)	0.34 (0.12)	0.52 (0.00)	0.46 (0.14)
July	**ITF**	0.44 (0.27)	0.49 (0.08)	0.34 (0.07)	0.27 (0.05)	0.10 (0.00)	0.37 (0.01)	0.56 (0.00)	0.25 (0.00)	0.48 (0.00)	0.48 (0.00)

	ITRT	0.44 (0.27)	0.49 (0.08)	0.23 (0.00)	0.49 (0.17)	0.44 (0.33)	0.29 (0.01)	0.40 (0.07)	0.35 (0.17)	0.36 (0.10)	0.33 (0.00)
	RTF	0.57 (0.30)	0.61 (0.13)	0.23 (0.06)	0.40 (0.09)	0.53 (0.15)	0.37 (0.17)	0.29 (0.09)	0.69 (0.02)	0.38 (0.00)	0.37 (0.00)
	RTRT	0.57 (0.30)	0.61 (0.13)	0.55 (0.11)	0.43 (0.15)	0.08 (0.01)	0.53 (0.14)	0.36 (0.01)	0.44 (0.11)	0.34 (0.04)	0.29 (0.74)
	SCF	0.53 (0.07)	0.37 (0.08)	0.34 (0.03)	0.34 (0.05)	0.17 (0.03)	0.69 (0.29)	0.45 (0.06)	0.43 (0.21)	0.55 (0.09)	0.51 (0.00)
	SCRT	0.53 (0.07)	0.37 (0.08)	0.48 (0.12)	0.50 (0.12)	0.52 (0.02)	0.54 (0.00)	0.35 (0.03)	0.67 (0.12)	0.25 (0.00)	0.54 (0.19)
September	**ITF**	0.72 (0.06)	0.60 (0.17)	0.17 (0.01)	0.26 (0.05)	0.40 (0.02)	0.37	0.41 (0.03)	0.26 (0.09)	0.38 (0.25)	0.53 (0.00)
	ITRT	0.72 (0.06)	0.60 (0.17)	0.22 (0.06)	0.10 (0.00)	0.47 (0.17)	0.29	0.86 (0.00)	0.45 (0.34)	0.32 (0.15)	0.07 (0.00)
	RTF	0.59 (0.34)	0.49 (0.15)	0.43 (0.05)	0.49 (0.09)	0.85 (0.02)	0.32	0.35 (0.12)	0.45 (0.03)	0.33 (0.17)	0.80 (0.09)
	RTRT	0.59 (0.34)	0.49 (0.15)	0.12 (0.00)	0.31 (0.03)	0.68 (0.00)	0.40 (0.00)	0.26 (0.00)	0.22 (0.03)	0.09 (0.05)	0.61

	SCF	0.62 (0.07)	0.45 (0.14)	0.53 (0.12)	0.67 (0.10)	0.85 (2.20)	0.26	0.33 (0.00)	0.30 (0.08)	0.70 (0.00)	0.13 (0.05)
	SCRT	0.62 (0.07)	0.45 (0.14)	0.43 (0.22)	0.09 (0.00)	0.21 (0.03)	0.63	0.46 (0.23)	0.42 (0.10)	0.49 (0.12)	0.53 (0.14)
All Season	**ITF**	0.51 (0.09)	0.48 (0.09)	0.34 (0.06)	0.39 (0.07)	0.45 (0.04)	0.37 (0.03)	0.47 (0.04)	0.30 (0.07)	0.48 (0.00)	0.48 (0.05)
	ITRT	0.51 (0.09)	0.48 (0.09)	0.28 (0.04)	0.44 (0.08)	0.47 (0.22)	0.40 (0.10)	0.48 (0.09)	0.36 (0.11)	0.47 (0.09)	0.43 (0.17)
	RTF	0.51 (0.16)	0.48 (0.09)	0.35 (0.04)	0.46 (0.05)	0.53 (0.15)	0.34 (0.03)	0.32 (0.06)	0.50 (0.05)	0.35 (0.09)	0.53 (0.09)
	RTRT	0.51 (0.16)	0.48 (0.09)	0.53 (0.10)	0.37 (0.06)	0.48 (0.01)	0.49 (0.11)	0.32 (0.02)	0.30 (0.06)	0.34 (0.04)	0.37
	SCF	0.64 (0.06)	0.42 (0.08)	0.49 (0.07)	0.51 (0.09)	0.57 (0.07)	0.56 (0.21)	0.40 (0.04)	0.34 (0.06)	0.54 (0.05)	0.51 (0.02)
	SCRT	0.64 (0.06)	0.42 (0.08)	0.47 (0.07)	0.45 (0.08)	0.33 (0.14)	0.53 (0.12)	0.46 (0.09)	0.47 (0.08)	0.47 (0.07)	0.50 (0.08)

Table 64 Probability for the Mean Lutein Values of Tomatoes. Fruits were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated meaures GLM.

Source of Variation	Probability
Day	0.681
Month	0.724
Pre-sale Treatment	0.042
Post-sale Treatment	0.273
Day x Month	0.519
Day x Pre-sale Treatment	0.131
Day x Post-sale Treatment	0.121
Month x Pre-sale Treatment	0.009
Month x Post-sale Treatment	0.790
Pre-sale Treatment x Post-sale Treatment	0.114

Table 65 Mean Sum of Phenolic Compounds of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets represent standard error.

		Sum of Total Phenolic Compounds µg/g FW									
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	5471.34 (85.77)	5973.11 (1014.12)	6911.33 (611.08)	8235.00 (1162.15)	10916.39 (7072.98)	7387.83	8066.06 (2230.02)	5348.92 (2382.42)	9740.38 (243.71)	10411.38 (1596.15)
	ITRT	5471.34 (85.77)	5973.11 (1014.12)	7327.93 (896.24)	7701.17 (1487.57)	9148.74 (239.60)	6346.39	11013.83 (8145.6)	6545.35 (4468.47)	7717.95 (4436.430	11652.20 (730.51)
	RTF	4893.04 (1434.18)	5883.58 (517.49)	8258.37 (1713.66)	10688.49 (4387.08)	7347.23 (2814.13)	7773.33	2648.89 (39.03)	8383.43 (4336.63)	7927.70 (928.18)	11050.17 (1586.12)
	RTRT	4893.04 (1434.18)	5883.58 (517.49)	6954.57 (606.37)	6177.88 (532.38)	7986.25 (340.87)	4306.58 (816.41)	3008.35 (8925.18)	4894.93 (1317.85)	4933.34 (1227.03)	10266.75 (973.38)
	SCF	3013.72 (39.03)	4288.34 (710.34)	7522.90 (2666.08)	5141.80 (1651.42)	7101.73 (622.92)	5481.27	7645.35 (2617.84)	4988.71 (1825.73)	7791.38 (976.94)	10830.73 (1625.74)
	SCRT	3013.72 (39.03)	4288.34 (710.34)	4211.78 (841.00)	17371.50 (841.00)	8445.51 (804.17)	5860.39	8250.13 (3390.71)	6391.24 (4203.38)	5585.28 (1603.25)	11195.11 (1161.45)

July	**ITF**	2941.71 (990.29)	3523.12 (767.520	6479.06 (1838.63)	4398.81 (798.89)	6051.91 (587.58)	5114.66 (2336.14)	10252.15 (1878.59)	6636.27 (5372.91)	7888.76 (2817.61)	10791.57 (1586.12)
	ITRT	2941.71 (990.29)	3523.12 (767.520	7478.97 (2647.65)	4699.97 (1757.43)	8057.03 (940.12)	7516.02 (3371.86)	5010.55 (2152.65)	3566.17 (1521.70)	13507.85 (1781.21)	11854.87 (1028.38)
	RTF	2846.49 (320.65)	7716.38 (3210.66)	4676.69 (380.69)	4422.17 (3182.16)	7347.23 (1056.94)	9488.67 (1387.12)	12569.19 (2.20)	6408.06 (2303.84)	8698.35 (784.22)	10284.97 (1783.21)
	RTRT	2846.49 (320.65)	7716.38 (3210.66)	7411.58 (91.37)	9130.58 (672.83)	9490.86 (1293.54)	9303.62 (1584.26)	7475.52 (857.75)	7289.32 (23.27)	17059.87 (1213.04)	6945.75 (792.13)
	SCF	2782.92 (336.92)	8852.82 (4833.05)	5852.00 (1205.13)	9510.08 (397.64)	7205.58 (459.15)	5824.66 (1229.25)	9868.30 (539.93)	9883.46 (7647.55)	6589.68 (4241.04)	9980.37 (181.26)
	SCRT	2782.92 (336.92)	8852.82 (4833.05)	6532.59 (1975.49)	8277.84 (0.12)	6853.79 (205.86)	7940.90 (2303.84	8302.67 (295.65)	7988.32 (295.67)	9657.74 (5498.82)	14824.58 (8876.55)
September	**ITF**	4408.86 (1597.47)	9914.91 (3673.37)	10328.54 (2648.68)	8674.76 (2838.77)	4392.50 (1121.56)	9555.75	9108.11 (3672.11)	7657.76 (5469.75)	9299.67 (218.69)	9496.67 (1516.39)
	ITRT	4408.86 (1597.47)	9914.91 (3673.37)	9680.58 (5026.81)	6460.43 (1482.76)	8027.17 (2384.67)	7620.54	7272.59 (1321.61)	3332.39 (9789.2)	7120.60 (2856.76)	6918.75 (492.17)
	RTF	5357.01 (1659.70)	6261.05 (5227.83)	8884.98 (5923.92)	5221.30 (914.16)	8841.97 (1182.3.8)	7942.82	6365.51 (1991.34)	8334.73 (829.52)	5710.45 (2287.88)	9602.72 (502.63)

	RTRT	5357.01 (1659.70)	6261.05 (5227.83)	6463.88 (1574.73)	9844.59 (4951.34)	8218.64 (459.22)	7200.26 (1058.68)	12492.61 (6706.37)	8651.52 (5613.60)	14115.42 (3025.11)	13043.83
	SCF	4155.39 (736.28)	4313.46 (2023.85)	5185.82 (1391.83)	8369.68 (1984.51)	7691.94 (604.25)	6025.54	7260.13 (2410.01)	6769.93 (4960.13)	9980.37 (982.31)	8768.33 (750.98)
	SCRT	4155.39 (736.28)	4313.46 (2023.85)	7126.90 (113.86)	3053.86 (299.94)	10774.40 (961.23)	12123.15	4225.95 (71.65)	7850.00 (6081.81)	7200.91 (8319.50)	8463.91 (1659.95)
All Season	**ITF**	4106.94 (578.01)	7441.26 (1406.19)	9325.31 (1149.66)	8173.20 (1117.72)	6577.89 (1632.370	6596.36 (355.59)	9556.26 (1848.26)	9204.15 (2030.29)	6406.22 (1804.67)	10299.82 (1757.29)
	ITRT	4106.94 (578.01)	7441.26 (1406.19)	8162.49 (1579.53)	9753.55 (1610.36)	8263.43 (345.26)	7419.26 (917.53)	8206.90 (995.47)	7709.40 (707.79)	8637.01 (1116.00)	9646.84 (609.72)
	RTF	4504.04 (180.72)	8517.77 (1312.25)	7202.42 (1481.53)	7751.72 (1365.81)	7845.48 (166.08)	7877.70 (939.62)	7609.05 (1011.88)	9696.01 (1903.79)	7881.75 (729.91)	10312.64 (421.09)
	RTRT	4504.04 (180.72)	8517.77 (1312.25)	7303.38 (709.26)	7780.99 (980.98)	8565.25 (476.12)	7500.08 (243.53)	10578.92 (801.60)	8655.92 (1895.47)	10236.82 (15.92)	11743.79 (1455.60)
	SCF	3103.18 (306.91)	7088.00 (1521.58)	6258.35 (1133.06)	7960.51 (1566.35)	7309.95 (242.73)	5655.69 (421.67)	6157.05 (2491.83)	7289.94 (2992.88)	7748.49 (1273.51)	9859.80 (498.92)
	SCRT	3103.18 (306.91)	7088.00 (1521.58)	6180.80 (808.63)	7096.31 (1688.47)	8656.13 (465.98)	7132.44 (134.69)	8136.72 (2204.68)	8944.74 (2583.94)	11237.69 (2260.58)	9447.79 (580.71)

Table 66 Mean Total Soluble Solids (TSS) (°Brix) of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets show standard error. *data not recorded.

Total Soluble Solids (TSS) (°Brix)											
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	4.13 (0.02)	4.17 (0.01)	4.35 (0.06)	4.27 (0.01)	4.26 (0.00)	4.31 (0.00)	4.28 (0.00)	4.28 (0.05)	4.25 (0.00)	*
	ITRT	4.13 (0.07)	4.17 (0.01)	4.38 (0.02)	4.34 (0.04)	4.34 (0.00)	4.23 (0.00)	4.10 (0.00)	4.37 (0.00)	4.37 (0.00)	*
	RTF	4.19 (0.07)	4.25 (0.02)	4.14 (0.01)	4.27 (0.09)	4.40 (0.00)	4.27 (0.00)	4.31 (0.00)	4.25 (0.04)	4.20 (0.00)	*
	RTRT	4.19 (0.07)	4.25 (0.01)	4.53 (0.09)	4.38 (0.01)	4.26 (0.00)	4.45 (0.00)	4.37 (0.00)	4.20 (0.10)	4.00 (0.00)	*
	SCF	4.18 (0.07)	4.13 (0.02)	4.23 (0.00)	4.23 (0.01)	4.43 (0.00)	4.45 (0.00)	4.30 (0.00)	4.18 (0.00)	4.10 (0.00)	*
	SCRT	4.18 (0.07)	4.13 (0.02)	4.29 (0.05)	4.28 (0.06)	4.29 (0.00)	4.29 (0.00)	4.48 (0.00)	4.38 (0.02)	4.40 (0.00)	*

	Average	4.17 (0.05)	4.19 (0.01)	4.32 (0.04)	4.29 (0.03)	4.33 (0.00)	4.37 (0.00)	4.31 (0.00)	4.28 (0.04)	4.22 (0.00)	*
July	**ITF**	4.26 (0.13)	4.12 (0.01)	4.23 (0.02)	4.37 (0.02)	4.38 (0.00)	4.33 (0.01)	4.22 (0.03)	4.21 (0.03)	4.23 (0.03)	4.16 (0.01)
	ITRT	4.26 (0.13)	4.12 (0.010	4.35 (0.02)	4.27 (0.03)	4.38 (0.02)	4.17 (0.01)	4.61 (0.00)	4.51 (0.01)	4.44 (0.01)	4.40 (0.05)
	RTF	4.16 (0.02)	4.20 (0.00)	4.11 (0.01)	4.45 (0.03)	4.47 (0.03)	4.26 (0.03)	4.26 (0.01)	4.33 (0.01)	4.13 (0.02)	4.26 (0.01)
	RTRT	4.16 (0.02)	4.20 (0.00)	4.5 (0.02)	4.48 (0.02)	4.27 (0.01)	4.23 (0.03)	4.31 (0.04)	4.13 (0.03)	4.30 (0.03)	4.46 (0.02)
	SCF	4.10 (0.02)	4.10 (0.00)	4.14 (0.01)	4.14 (0.03)	4.38 (0.08)	4.27 (0.00)	4.29 (0.03)	4.28 (0.04)	4.24 (0.07)	4.44 (0.01)
	SCRT	4.16 (0.02)	4.10 (0.0)	4.37 (0.02)	4.38 (0.06)	4.48 (0.00)	4.36 (0.04)	4.32 (0.04)	4.31 (0.03)	4.44 (0.03)	4.37 (0.03)
	Average	4.17 (0.06)	4.14 (0.01)	4.29 (0.02)	4.35 (0.03)	4.39 (0.03)	4.27 (0.02)	4.34 (0.02)	4.29 (0.02)	4.30 (0.03)	4.35 (0.02)
September	**ITF**	4.00 (0.03)	4.11 (0.02)	4.24 (0.02)	4.34 (0.00)	4.28 (0.02)	4.31 (0.03)	4.25 (0.01)	4.28 (0.00)	*	*

	ITRT	4.00 (0.03)	4.11 (0.02)	4.38 (0.02)	4.37 (0.02)	4.25 (0.05)	4.22 (0.04)	4.27 (0.03)	4.40 (0.00)	*	4.32 (0.04)
	RTF	3.97 (0.05)	4.14 (0.01)	4.23 (0.06)	4.43 (0.02)	4.32 (0.01)	4.27 (0.02)	4.30 (0.01)	4.26 (0.02)	*	*
	RTRT	3.97 (0.05)	4.14 (0.01)	4.46 (0.03)	4.41 (0.04)	4.28 (0.06)	4.45 (0.01)	4.39 (0.01)	4.30 (0.00)	*	4.45 (0.02)
	SCF	4.01 (0.04)	4.05 (0.02)	4.22 (0.02)	4.33 (0.05)	4.45 (0.01)	4.24 (0.00)	4.20 (0.06)	4.17 (0.00)	*	*
	SCRT	4.01 (0.04)	4.05 (0.02)	4.29 (0.02)	4.45 (0.01)	4.29 (0.00)	4.38 (0.03)	4.42 (0.03)	4.39 (0.00)	*	4.21 (0.00)
	Average	3.99 (0.04)	4.10 (0.02)	4.30 (0.03)	4.39 (0.02)	4.31 (0.02)	4.31 (0.02)	4.30 (0.02)	4.30 (0.01)	*	4.33 (0.01)
All Season	**ITF**	4.13 (0.06)	4.13 (0.01)	4.21 (0.02)	4.24 (0.03)	4.19 (0.03)	4.21 (0.07)	4.24 (0.03)	4.27 (0.02)	4.27 (0.01)	4.26 (0.01)
	ITRT	4.13 (0.06)	4.13 (0.01)	4.24 (0.02)	4.30 (0.02)	4.38 (0.02)	4.30 (0.07)	4.44 (0.03)	4.39 (0.05)	4.43 (0.07)	4.431 (0.01)
	RTF	4.10 (0.04)	4.20 (0.01)	4.29 (0.02)	4.28 (0.02)	4.31 (0.03)	4.37 (0.05)	4.41 (0.03)	4.41 (0.02)	4.42 (0.03)	4.45 (0.01)

	RTRT	4.10 (0.04)	4.20 (0.01)	4.31 (0.02)	4.32 (0.01)	4.33 (0.04)	4.36 (0.08)	4.47 (0.03)	4.43 (0.06)	4.44 (0.07)	4.44 (0.02)
	SCF	4.09 (0.03)	4.09 (0.01)	4.16 (0.02)	4.22 (0.04)	4.24 (0.03)	4.28 (0.03)	4.29 (0.03)	4.27 (0.03)	4.26 (0.01)	4.24 (0.01)
	SCRT	4.09 (0.03)	4.09 (0.01)	4.24 (0.02)	4.30 (0.03)	4.26 (0.04)	4.31 (0.05)	4.45 (0.05)	4.43 (0.05)	4.37 (0.05)	4.40 (0.01)

Table 67 Probability for the Mean Total Soluble Solids, pH, Citric acid and Vitamin C Contents of Tomatoes at Day 0 and Day 7. Fruits were stored either at IT (15˚C), RT (23˚C) or SC (average 12˚C). Data was analysed by GLM.

		Total soluble solids (◦Brix)	Vitamin C mg/100g FW	pH	Citric Acid g/100g FW
Day	**Source of Variation**	**Probability**			
0	**Month**	<0.001	0.128	0.007	0.014
	Treatment	0.857	0.247	0.668	0.441
	Month x Treatment	0.660	0.774	0.557	0.649
7	**Month**	<0.001	0.098	<0.001	<0.001
	Treatment	<0.001	0.500	0.312	0.218
	Month x Treatment	0.453	0.858	0.941	0.831

Table 68 Probability for the Total Soluble Solids, pH, Citric Acid and Vitamin C of Tomatoes. Fruits were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was analysed by repeated measures GLM.

	Probability			
Source of Variation	**Total Soluble Solids (◦Brix)**	**Vitamin C mg/100g FW**	**pH**	**Citric Acid g/100g FW**
Day	<0.001	0.280	<0.001	<0.001
Month	<0.001	<0.001	<0.001	<0.001
Pre-sale Treatment	0.054	0.075	0.562	0.005
Post-Sale Treatment	0.339	0.023	0.091	<0.001
Day x Month	<0.001	<0.001	<0.001	<0.001
Day x Pre-sale Treatment	0.671	0.180	0.951	0.270
Day x Post-sale Treatment	0.099	<0.001	0.054	0.408
Month x Pre-sale Treatment	0.002	0.020	0.539	0.472
Month x Post-sale Treatment	<0.001	0.274	0.002	0.001
Pre-sale Treatment x Post-sale Treatment	<0.001	0.290	0.886	<0.001

Table 69 Mean Vitamin C Levels of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets show standard error. *data not recorded.

		Vitamin C mg/100g FW									
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	11.31 (2.57)	10.39 (1.09)	15.44 (0.57)	12.34 (0.37)	11.68 (0.03)	11.21 (0.02)	14.10 (0.04)	11.04 (0.07)	9.69 (0.03)	*
	ITRT	11.31 (2.57)	10.39 (1.09)	13.17 (0.26)	12.85 (0.55)	12.55 (0.54)	13.97 (0.96)	10.36 (1.13)	12.11 (0.91)	9.47 (0.02)	*
	RTF	8.02 (0.45)	10.15 (1.12)	16.64 (0.12)	13.36 (0.15)	15.43 (0.46)	15.80 (0.68)	10.24 (0.02)	10.50 (0.02)	9.80 (0.02)	*
	RTRT	8.02 (0.45)	10.15 (1.12)	12.06 (0.73)	12.06 (0.10)	17.85 (0.45)	15.50 (0.97)	12.77 (0.44)	14.75 (1.63)	14.65 (2.36)	*
	SCF	10.61 (2.44)	10.51 (1.33)	11.77 (0.20)	9.76 (0.15)	11.81 (0.77)	11.75 (0.13)	12.56 (0.69)	14.66 (0.94)	14.68 (0.72)	*
	SCRT	10.61 (2.44)	10.51 (1.33)	15.37 (0.66)	10.08 (1.67)	15.96 (0.80)	15.07 (0.04)	12.41 (0.95)	12.15 (0.08)	11.32 (0.30)	*

	Average	9.98 (1.82)	10.35 (1.18)	14.08 (0.42)	11.74 (0.50)	14.21 (0.51)	13.88 (0.47)	12.07 (0.54)	12.54 (0.61)	11.60 (0.57)	*
July	**ITF**	11.06 (1.12)	11.83 (0.81)	11.77 (0.16)	15.19 (0.75)	13.86 (0.24)	11.53 (0.03)	12.91 (0.25)	11.37 (0.43)	11.10 (0.27)	15.26 (1.13)
	ITRT	11.06 (1.12)	11.83 (0.81)	13.16 (0.84)	13.66 (0.49)	13.22 (0.69)	14.87 (0.06)	11.91 (1.00)	12.06 (0.73)	8.96 (0.10)	8.51 (0.31)
	RTF	10.47 (0.98)	13.26 (1.63)	14.06 (0.64)	13.73 (0.41)	15.67 (0.02)	13.20 (0.35)	11.36 (0.25)	10.83 (0.21)	11.15 (0.27)	10.75 (0.44)
	RTRT	10.47 (0.98)	13.26 (1.63)	12.84 (0.82)	8.02 (0.21)	18.12 (0.64)	15.24 (0.61)	12.08 (0.42)	13.32 (1.51)	15.81 (0.87)	16.39 (0.93)
	SCF	10.93 (0.81)	12.23 (1.02)	16.88 (1.11)	8.92 (0.14)	10.64 (0.12)	11.56 (0.12)	12.46 (0.22)	12.21 (0.70)	14.68 (0.45)	14.45 (0.48)
	SCRT	10.93 (0.81)	12.23 (1.02)	15.42 (0.29)	12.06 (0.31)	12.14 (0.10)	14.86 (0.13)	12.06 (0.31)	12.67 (0.27)	14.03 (0.70)	12.05 (0.78)
	Average	10.82 (0.97)	12.44 (1.15)	14.02 (0.64)	11.93 (0.39)	13.94 (0.30)	13.54 (0.22)	12.13 (0.41)	12.08 (0.64)	12.62 (0.44)	12.90 (0.68)
September	**ITF**	12.29 (1.34)	11.47 (1.16)	14.56 (0.45)	15.35 (0.99)	11.05 (0.04)	10.04 (0.00)	10.18 (0.02)	9.98 (0.10)	*	*

	ITRT	12.29 (1.34)	11.47 (1.16)	11.23 (0.48)	12.53 (0.08)	12.13 (0.12)	15.05 (0.09)	13.47 (0.86)	11.55 (1.30)	*	8.26 (0.47)
	RTF	11.40 (0.94)	14.39 (2.18)	12.88 (0.13)	15.49 (0.29)	15.30 (0.16)	11.63 (0.04)	11.45 (0.02)	10.80 (0.02)	*	*
	RTRT	11.40 (0.94)	14.39 (2.18)	9.78 (0.19)	11.22 (2.57)	14.82 (1.22)	14.29 (0.20)	12.71 (0.80)	18.05 (1.16)	*	13.05 (3.14)
	SCF	12.47 (1.01)	12.36 (1.60)	11.82 (1.19)	10.64 (0.77)	14.82 (0.41)	13.79 (1.19)	12.46 (1.23)	14.12 (1.16)	*	*
	SCRT	12.47 (1.01)	12.36 (1.60)	10.62 (2.66)	12.67 (0.38)	15.77 (0.530	6.38 (4.17)	7.75 (2.77)	13.16 (0.610	*	11.35 (0.99)
	Average	12.20 (1.10)	12.74 (1.64)	11.81 (0.85)	12.98 (0.85)	13.98 (0.41)	11.86 (0.95)	11.34 (0.95)	12.94 (0.72)	*	10.89 (1.53)
All Season	**ITF**	11.57 (0.76)	11.23 (0.69)	12.19 90.39)	14.65 (1.51)	11.32 (0.62)	13.76 (0.43)	11.25 (0.65)	11.64 (0.61)	12.42 (0.55)	12.16 (0.48)
	ITRT	11.57 (0.76)	11.23 (0.69)	13.01 (0.55)	15.55 (1.85)	11.85 (0.55)	12.53 (0.59)	12.44 (0.78)	14.35 (0.94)	15.34 (1.22)	12.45 (0.49)
	RTF	10.08 (0.58)	12.60 (1.02)	13.91 (0.56)	15.16 (1.35)	11.07 (0.40)	14.20 (0.54)	12.12 (0.69)	12.73 (0.97)	12.62 (0.70)	12.64 (0.60)

RTRT	10.08 (0.58)	12.60 (1.02)	14.02 (0.68)	13.29 (0.65)	12.39 (0.65)	13.53 (0.82)	12.09 (0.77)	13.64 (0.95)	16.06 (0.70)	14.14 (0.49)
SCF	11.49 (0.75)	11.70 (0.75)	12.24 (0.58)	14.56 (1.32)	11.02 (0.62)	13.71 (0.58)	9.71 (0.50)	11.80 (0.87)	10.48 (1.69)	8.60 (1.63)
SCRT	11.49 (0.75)	11.70 (0.75)	12.80 (0.48)	13.06 (0.69)	10.63 (0.15)	13.37 (0.76)	11.86 (0.62)	12.42 (0.81)	14.30 (0.46)	13.72 (0.53)

Table 70 Mean pH Levels of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets show standard error. *data not recorded.

pH											
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	4.45 (0.09)	4.23 (0.03)	4.32 (0.02)	4.18 (0.01)	4.95 (0.42)	5.47 (0.10)	5.17 (0.08)	4.90 (0.06)	4.77 (0.16)	*
	ITRT	4.45 (0.09)	4.23 (0.03)	5.09 (0.23)	4.98 (0.08)	4.97 (0.01)	5.02 (0.00)	4.85 (0.03)	5.49 (0.08)	5.17 (0.04)	*
	RTF	4.19 (0.07)	4.00 (0.00)	4.33 (0.00)	4.28 (0.05)	4.92 (0.20)	5.47 (0.14)	5.13 (0.08)	4.90 (0.07)	5.06 (0.14)	*
	RTRT	4.19 (0.07)	4.00 (0.00)	5.18 (0.03)	4.41 (0.01)	4.37 (0.09)	4.31 (0.00)	5.24 (0.04)	5.02 (0.02)	4.97 (0.03)	*
	SCF	4.17 (0.11)	4.23 (0.03)	4.93 (0.00)	4.95 (0.01)	4.69 (0.00)	4.83 (0.16)	4.41 (0.02)	4.22 (0.03)	4.25 (0.01)	*
	SCRT	4.17 (0.11)	4.23 (0.03)	5.00 (0.04)	5.00 (0.02)	5.47 (0.21)	5.40 (0.08)	5.55 (0.17)	5.38 (0.03)	4.68 (0.10)	*

	Average	4.27 (0.09)	4.16 (0.02)	4.81 (0.05)	4.63 (0.03)	4.89 (0.15)	5.08 (0.08)	5.06 (0.07)	4.99 (0.05)	4.81 (0.08)	*
July	**ITF**	4.65 (0.05)	4.40 (0.12)	4.33 (0.00)	4.22 (0.00)	4.21 (0.00)	5.21 (0.00)	4.92 (0.17)	5.09 (0.00)	4.47 (0.00)	4.24 (0.02)
	ITRT	4.65 (0.05)	4.40 (0.12)	4.81 (0.40)	5.04 (0.06)	5.03 (0.00)	5.03 (0.00)	4.92 (0.01)	5.49 (0.06)	5.49 (0.06)	5.51 (0.04)
	RTF	4.90 (0.00)	4.33 (0.09)	4.15 (0.00)	4.57 (0.38)	4.86 (0.00)	5.43 (0.00)	5.26 (0.17)	4.81 (0.06)	5.21 (0.11)	5.17 (0.04)
	RTRT	4.90 (0.00)	4.33 (0.09)	5.15 (0.06)	4.44 (0.01)	4.18 (0.00)	5.21 (0.00)	5.09 (0.01)	5.03 (0.07)	4.93 (0.01)	4.98 (0.05)
	SCF	4.70 (0.30)	4.37 (0.16)	4.87 (0.08)	4.97 (0.01)	4.75 (0.00)	4.98 (0.00)	4.38 (0.00)	4.29 (0.02)	5.55 (0.11)	5.36 (0.10)
	SCRT	4.70 (0.30)	4.37 (0.16)	5.01 (0.06)	4.94 (0.01)	4.92 (0.00)	5.43 (0.00)	5.26 (0.06)	5.49 (0.06)	5.49 (0.17)	5.43 (0.00)
	Average	4.75 (0.08)	4.37 (0.12)	4.72 (0.10)	4.70 (0.08)	4.66 (0.01)	5.21 (0.01)	4.97 (0.07)	5.03 (0.04)	5.19 (0.08)	5.12 (0.04)
September	**ITF**	4.50 (0.30)	4.90 (0.20)	4.22 (0.10)	4.27 (0.00)	5.66 (0.00)	5.32 (0.00)	5.32 (0.00)	4.75 (0.00)	*	*

	ITRT	4.50 (0.30)	4.90 (0.20)	5.26 (0.06)	5.02 (0.01)	5.00 (0.00)	5.03 (0.00)	4.80 (0.00)	5.55 (0.00)	*	5.55 (0.00)
	RTF	4.40 (0.20)	4.77 (0.23)	4.23 (0.11)	4.86 (0.05)	5.77 (0.00)	5.32 (0.00)	4.98 (0.00)	4.98 (0.00)	*	*
	RTRT	4.40 (0.20)	4.77 (0.23)	4.39 (0.00)	4.33 (0.13)	4.46 (0.00)	4.98 (0.00)	5.09 (0.00)	5.09 (0.00)	*	5.08 (0.00)
	SCF	4.50 (0.20)	4.90 (0.00)	4.80 (0.00)	4.75 (0.00)	4.75 (0.00)	4.98 (0.00)	4.39 (0.00)	4.15 (0.00)	*	*
	SCRT	4.50 (0.20)	4.90 (0.00)	5.09 (0.00)	4.93 (0.01)	5.43 (0.00)	5.32 (0.00)	5.43 (0.00)	5.32 (0.00)	*	5.66 (0.00)
	Average	4.47 (0.23)	4.86 (0.14)	4.66 (0.04)	4.69 (0.03)	5.18 (0.01)	5.16 (0.01)	5.00 (0.01)	4.97 (0.01)	*	5.43 (0.01)
All Season	**ITF**	4.89 (0.17)	4.84 (0.25)	4.70 (0.16)	4.78 (0.19)	4.85 (0.11)	4.68 (0.26)	5.08 (0.10)	4.85 (0.15)	5.08 (0.10)	5.36 (0.04)
	ITRT	4.89 (0.17)	4.84 (0.25)	4.83 (0.19)	4.78 (0.16)	4.89 (0.10)	4.49 (0.18)	5.08 (0.10)	4.93 (0.12)	5.16 (0.05)	5.15 (0.18)
	RTF	4.80 (0.22)	4.80 (0.25)	4.83 (0.16)	4.73 (0.16)	5.04 (0.05)	4.78 (0.25)	5.15 (0.08)	4.92 (0.14)	5.19 (0.10)	5.43 (0.00)

RTRT	4.80 (0.22)	4.80 (0.25)	4.83 (0.18)	4.88 (0.13)	4.98 (0.09)	4.80 (0.24)	5.15 (0.08)	4.93 (0.14)	5.29 (0.15)	5.35 (0.21)
SCF	4.76 (0.21)	4.83 (0.20)	4.79 (0.16)	4.69 (0.17)	4.87 (0.07)	4.59 (0.28)	5.03 (0.12)	4.82 (0.17)	5.16 (0.14)	5.55 (0.07)
SCRT	4.76 (0.21)	4.83 (0.20)	4.79 (0.21)	4.79 (0.17)	4.91 (0.02)	4.62 (0.27)	5.08 (0.08)	4.86 (0.11)	5.12 (0.11)	5.23 (0.25)

Table 71 Mean Citric Acid Levels of Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets show standard error. *data not recorded.

		Citric Acid g/100g FW									
		Day									
Month	**Treatment**	**0**	**7**	**11**	**15**	**20**	**23**	**26**	**30**	**35**	**40**
May	**ITF**	0.493 (0.01)	0.453 (0.02)	0.435 (0.03)	0.429 (0.02)	0.288 (0.02)	0.320 (0.01)	0.309 (0.01)	0.400 (0.01)	0.411 (0.02)	*
	ITRT	0.493 (0.01)	0.453 (0.02)	0.245 (0.01)	0.328 (0.01)	0.283 (0.01)	0.395 (0.01)	0.261 (0.01)	0.245 (0.01)	0.283 (0.01)	*
	RTF	0.512 (0.01)	0.488 (0.02)	0.381 (0.00)	0.371 (0.02)	0.363 (0.02)	0.379 (0.04)	0.331 (0.01)	0.301 (0.02)	0.373 (0.01)	*
	RTRT	0.512 (0.01)	0.488 (0.02)	0.293 (0.04)	0.259 (0.00)	0.240 (0.00)	0.277 (0.01)	0.277 (0.01)	0.347 (0.02)	0.272 (0.00)	*
	SCF	0.520 (0.01)	0.709 (0.03)	0.352 (0.02)	0.405 (0.02)	0.341 (0.01)	0.352 (0.01)	0.373 (0.01)	0.341 (0.02)	0.315 (0.01)	*
	SCRT	0.520 (0.01)	0.709 (0.03)	0.272 (0.01)	0.283 (0.01)	0.368 (0.01)	0.261 (0.01)	0.331 (0.01)	0.317 (0.02)	0.261 (0.01)	*

	Average	0.508 (0.01)	0.550 (0.01)	0.330 (0.01)	0.345 (0.01)	0.314 (0.01)	0.331 (0.01)	0.314 (0.01)	0.325 (0.01)	0.319 (0.01)	*
July	**ITF**	0.387 (0.05)	0.352 (0.01)	0.472 (0.02)	0.360 (0.02)	0.283 (0.04)	0.347 (0.01)	0.331 (0.01)	0.381 (0.01)	0.453 (0.03)	0.437 (0.02)
	ITRT	0.387 (0.05)	0.352 (0.01)	0.291 (0.01)	0.395 (0.03)	0.325 (0.01)	0.400 (0.01)	0.301 (0.02)	0.272 (0.03)	0.280 (0.00)	0.272 (0.03)
	RTF	0.437 (0.05)	0.312 (0.01)	0.419 (0.02)	0.437 (0.03)	0.320 (0.03)	0.384 (0.01)	0.309 (0.00)	0.320 (0.01)	0.344 (0.01)	0.366 (0.01)
	RTRT	0.437 (0.05)	0.312 (0.01)	0.245 (0.01)	0.235 (0.01)	0.373 (0.01)	0.373 (0.01)	0.309 (0.00)	0.376 (0.01)	0.272 (0.01)	0.376 (0.01)
	SCF	0.467 (0.02)	0.357 (0.00)	0.336 (0.01)	0.280 (0.01)	0.373 (0.01)	0.282 (0.01)	0.336 (0.01)	0.331 (0.01)	0.395 (0.02)	0.331 (0.02)
	SCRT	0.467 (0.02)	0.357 (0.00)	0.293 (0.02)	0.301 (0.01)	0.245 (0.05)	0.240 (0.00)	0.285 (0.01)	0.277 (0.03)	0.253 (0.01)	0.277 (0.02)
	Average	0.430 (0.03)	0.341 (0.01)	0.343 (0.01)	0.335 (0.01)	0.320 (0.01)	0.338 (0.01)	0.312 (0.01)	0.326 (0.01)	0.333 (0.01)	0.343 (0.01)
September	**ITF**	0.541 (0.06)	0.459 (0.01)	0.411 (0.01)	0.371 (0.01)	0.309 (0.01)	0.373 (0.01)	0.325 (0.01)	0.379 (0.01)	*	*

	ITRT	0.541 (0.06)	0.459 (0.01)	0.320 (0.01)	0.333 (0.03)	0.336 (0.04)	0.293 (0.01)	0.240 (0.01)	0.336 (0.01)	*	0.320 (0.00)
	RTF	0.459 (0.02)	0.454 (0.03)	0.413 (0.02)	0.355 (0.03)	0.357 (0.01)	0.315 (0.03)	0.309 (0.03)	0.299 (0.01)	*	*
	RTRT	0.459 (0.02)	0.454 (0.03)	0.272 (0.01)	0.355 (0.02)	0.288 (0.02)	0.352 (0.00)	0.389 (0.01)	0.389 (0.01)	*	0.309 (0.01)
	SCF	0.547 (0.03)	0.528 (0.02)	0.339 (0.01)	0.269 (0.01)	0.277 (0.01)	0.309 (0.01)	0.293 (0.01)	0.293 (0.01)	*	*
	SCRT	0.547 (0.03)	0.528 (0.02)	0.251 (0.01)	0.304 (0.01)	0.245 (0.01)	0.229 (0.01)	0.288 (0.00)	0.288 (0.01)	*	0.384 (0.02)
	Average	0.516 (0.04)	0.480 (0.02)	0.334 (0.01)	0.331 (0.02)	0.302 (0.02)	0.312 (0.01)	0.308 (0.01)	0.331 (0.01)	*	0.364 (0.01)
All Season	**ITF**	0.472 (0.03)	0.421 (0.01)	0.405 (0.01)	0.346 (0.01)	0.377 (0.01)	0.373 (0.01)	0.347 (0.01)	0.353 (0.01)	0.224 (0.06)	0.212 (0.05)
	ITRT	0.472 (0.03)	0.421 (0.01)	0.372 (0.01)	0.347 (0.01)	0.281 (0.01)	0.313 (0.02)	0.257 (0.01)	0.284 (0.01)	0.274 (0.01)	0.257 (0.01)
	RTF	0.488 (0.01)	0.418 (0.02)	0.380 (0.02)	0.380 (0.01)	0.316 (0.01)	0.304 (0.01)	0.292 (0.01)	0.294 (0.01)	0.244 (0.01)	0.247 (0.01)

RTRT	0.488 (0.01)	0.418 (0.02)	0.351 (0.02)	0.284 (0.01)	0.284 (0.01)	0.283 (0.01)	0.265 (0.01)	0.251 (0.01)	0.254 (0.01)	0.259 (0.00)
SCF	0.511 (0.02)	0.532 (0.05)	0.420 (0.01)	0.404 (0.01)	0.350 (0.01)	0.400 (0.02)	0.355 (0.01)	0.348 (0.01)	0.315 (0.01)	0.347 (0.02)
SCRT	0.511 (0.02)	0.532 (0.05)	0.378 (0.01)	0.352 (0.02)	0.336 (0.01)	0.313 (0.02)	0.260 (0.01)	0.274 (0.01)	0.290 (0.01)	0.272 (0.01)

Table 72 Probability for the Mean Surviving Tomatoes (%). Fruits were stored either for 7 days at IT (15˚C), RT (23˚) or SC (average 12˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Survival calculation was performed using the Kaplan-Meier Estimator (Kaplan and Meier, 1958)

Treatment	RTF	RTRT	SCF	SCRT	ITF	ITRT
p-value from chi-squared distribution table with 1 degree of freedom						
RTF		0.100	0.001	0.001	0.050	0.900
RTRT	0.100		0.900	0.001	0.900	0.900
SCF	0.001	0.900		0.001	0.025	0.001
SCRT	0.001	0.001	0.001		0.001	0.001
ITF	0.050	0.900	0.025	0.001		0.001
ITRT	0.900	0.900	0.001	0.001	0.001	

Table 73 Mean Percentage of Different Types of Disease Incidence or Wrinkling for Tomatoes Harvested in May, July and September. Tomatoes were stored for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C), and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Numbers in brackets show standard error.

Type of Death of Tomatoes by Termination of Study (%)										
Month	**Treatment**	**Total Decayed**	**Total Wrinkly**	**Total Decayed + Wrinkly**	**Anthracnose**	**Bacterial Soft Rot**	**Bacterial Spot**	**Blue Mould**	**Mucor**	**Rhizopus**
May	**ITF**	51.87 (9.58)	23.38 (8.70)	1.10 (1.10)	1.71 (1.71)	2.20 (1.49)	9.21 (4.89)	2.56 (2.56)	0.00 (0.00)	42.80 (10.56)
	ITRT	76.98 (9.47)	22.27 (9.22)	0.00 (0.00)	6.51 (4.60)	16.38 (7.19)	12.45 (4.80)	0.00 (0.00)	0.00 (0.00)	54.29 (11.43)
	RTF	81.39 (8.73)	8.91 (3.53)	1.01 (1.01)	5.62 (4.02)	7.28 (2.67)	12.24 (6.75)	0.00 (0.00)	0.00 (0.00)	68.08 (8.33)
	RTRT	71.17 (8.58)	21.39 (6.34)	0.00 (0.00)	11.19 (5.94)	15.29 (7.06)	13.14 (7.09)	0.00 (0.00)	0.00 (0.00)	49.39 (7.86)
	SCF	84.62 (5.52)	1.85 (1.31)	0.00 (0.00)	1.85 (1.31)	0.00 (0.00)	13.69 (3.90)	0.00 (0.00)	0.00 (0.00)	72.66 (5.72)
	SCRT	77.94 (9.13)	18.15 (9.08)	1.59 (1.59)	0.00 (0.00)	13.33 (8.82)	36.40 (12.59)	0.00 (0.00)	0.00 (0.00)	46.86 (8.60)

	Average	73.99 (8.50)	15.99 (6.36)	0.62 (0.62)	4.48 (2.93)	9.08 (4.54)	16.19 (6.67)	0.43 (0.43)	0.00 (0.00)	55.68 (8.75)
July	**ITF**	81.61 (6.34)	2.11 (1.46)	0.00 (0.00)	1.00 (1.00)	13.02 (6.20)	22.55 (6.06)	0.00 (0.00)	3.11 (2.24)	70.73 (6.90)
	ITRT	58.52 (10.29)	83.39 (8.16)	13.17 (4.57)	8.15 (6.73)	4.72 (2.72)	36.30 (8.41)	1.85 (1.29)	0.00 (0.00)	21.07 (8.10)
	RTF	101.82 (12.93)	21.95 (7.17)	0.00 (0.00)	1.68 (1.68)	27.68 (11.77)	36.38 (7.77)	0.00 (0.00)	0.00 (0.00)	87.15 (14.14)
	RTRT	58.06 (8.10)	59.06 (7.48)	15.76 (6.99)	16.54 (7.92)	10.74 (5.91)	30.58 (8.20)	0.00 (0.00)	0.00 (0.00)	24.69 (7.55)
	SCF	92.12 (3.79)	0.00 (0.00)	0.00 (0.00)	3.14 (2.22)	14.83 (7.17)	41.39 (7.01)	0.00 (0.00)	2.94 (2.9)	74.11 (6.56)
	SCRT	36.80 (8.78)	70.58 (9.17)	4.44 (3.44)	7.22 (5.32)	10.82 (6.05)	19.13 (8.91)	0.00 (0.00)	0.00 (0.00)	12.12 (5.49)
	Average	71.49 (8.37)	39.51 (5.57)	5.56 (2.50)	6.29 (4.14)	13.63 (6.64)	31.05 (7.73)	0.31 (0.22)	1.01 (0.86)	48.31 (8.12)
September	**ITF**	85.22 (6.12)	5.22 (2.27)	0.00 (0.00)	12.55 (5.53)	27.09 (7.52)	51.55 (7.34)	0.00 (0.00)	0.00 (0.00)	65.11 (7.48)

	ITRT	56.17 (8.81)	47.08 (10.08)	6.67 (4.54)	24.03 (7.74)	8.17 (4.05)	16.96 (5.15)	0.00 (0.00)	0.00 (0.00)	26.08 (7.09)
	RTF	75.37 (7.72)	12.02 (3.67)	2.32 (1.63)	4.64 (3.25)	8.06 (4.07)	29.70 (8.82)	0.00 (0.00)	0.00 (0.00)	53.31 (10.56)
	RTRT	48.50 (9.34)	63.05 (9.17)	10.11 (4.35)	19.78 (7.07)	8.11 (4.30)	22.91 (8.30)	2.22 (2.22)	0.00 (0.00)	22.65 (4.85)
	SCF	99.44 (0.56)	4.72 (2.83)	0.00 (0.00)	16.22 (5.72)	51.65 (8.59)	61.59 (9.54)	0.00 (0.00)	0.00 (0.00)	60.56 (9.53)
	SCRT	79.84 (6.88)	43.96 (8.730	1.80 (1.25)	21.87 (8.66)	3.39 (2.05)	25.38 (10.32)	0.00 (0.00)	0.00 (0.00)	39.05 (10.78)
	Average	74.09 (6.57)	29.34 (6.13)	3.48 (1.96)	16.52 (6.33)	17.88 (5.10)	34.68 (8.24)	0.37 (0.37)	0.00 (0.00)	44.46 (8.38)
All Season	**ITF**	75.49 (4.44)	8.56 (2.62)	0.27 (0.27)	5.40 (2.20)	15.75 (3.87)	29.81 (4.41)	0.64 (0.64)	1.20 (0.87)	62.52 (5.00)
	ITRT	62.25 (5.64)	71.89 (13.83)	7.44 (2.50)	13.69 (4.13)	8.93 (2.59)	23.58 (4.40)	0.69 (0.49)	0.00 (0.00)	40.01 (11.63)
	RTF	87.65 (6.40)	15.23 (3.32)	1.04 (0.61)	3.70 (1.63)	15.80 (5.14)	30.21 (6.09)	0.00 (0.00)	0.00 (0.00)	70.88 (7.28)

RTRT	57.15 (5.25)	66.65 (10.26)	10.00 (3.23)	17.20 (4.54)	10.70 (3.18)	24.75 (5.31)	0.89 (0.89)	0.00 (0.00)	29.36 (4.11)
SCF	93.58 (2.27)	2.31 (1.24)	0.00 (0.00)	8.23 (2.68)	26.86 (5.47)	45.81 (6.11)	0.00 (0.00)	1.14 (1.14)	68.27 (4.93)
SCRT	61.93 (5.85)	60.19 (10.22)	2.82 (1.49)	10.61 (3.92)	8.82 (3.31)	28.00 (6.98)	0.00 (0.00)	0.00 (0.00)	30.03 (5.36)

Table 74 Probability for the Percentage of Tomatoes Suffering from Different Types of Pathogens or Wrinkling by the Termination of the Study (%). Fruits were stored either for 7 days at IT (15˚C), RT (23˚C) or SC (average 12˚C); and for the remainder of the study at either ITF, RTF, SCF, ITRT, RTRT and SCRT. Data was anlaysed by GLM.

	Type of Pathogen or Wrinkling (%)								
	Total Decayed	Total Wrinkly	Total Decayed + Wrinkly	Anthracnose	Bacterial Soft Rot	Bacterial Spot	Blue Mould	Mucor	Rhizopus
Source of Variation	**Probability**								
Month	0.616	<0.001	0.031	<0.001	0.042	0.001	0.941	0.001	0.081
Pre-sale Treatment	0.103	0.077	0.146	0.895	0.532	0.136	0.411	0.148	0.696
Post-sale Treatment	<0.001	<0.001	<0.001	0.005	0.042	0.050	0.757	0.055	<0.001
Month x Pre-sale Treatment	0.003	0.345	0.720	0.372	0.040	0.406	0.365	0.431	0.323
Month x Post-sale Treatment	<0.001	<0.001	0.007	0.496	<0.001	0.002	0.273	0.003	<0.001
Pre-sale Treatment x Post-sale Treatment	0.220	0.316	0.199	0.334	0.179	0.376	0.689	0.392	0.739