OPTIMIZATION OF THE HANDLING PROCESSES FROM THE FARM TO THE STORE TO PROVIDE BETTER QUALITY STRAWBERRIES TO THE CONSUMERS

By

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To my parents

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LIST OF ABBREVIATIONS

°C	degrees Celsius
AA	ascorbic acid
C1	first harvest control
C2	second harvest control
$CO_2kg^{-1}h^{-1}$	carbon dioxide per kilogram per hour
cv.	cultivated variety, cultivar
d	day
DC	distribution center
DW	dry weight
F1	first harvest fluctuating
F2	second harvest fluctuating
FW	fresh weight
HCl	hydrochloric acid
HPLC	high performance liquid chromatography
KH_2PO_4	potassium dihydrogen phosphate
L*	lightness
LSD	least significant difference
$mL \cdot kg^{-1}h^{-1}$	mL per kilogram per hour
MW	molecular weight
N	normality
NaOH	sodium hydroxide
ns	not significant
PC	pre-cooling
PGN	pelargonidin-3-glucoside

PPO	polyphenol oxidase
RH	relative humidity
SSC	soluble solids content
TA	titratable acidity
v/v	volume to volume
w/v	weight per volume

Abstract of Thesis Presented to the Graduate School
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Strawberry fruit are fragile and deteriorate quickly if handled under adverse conditions. Long transit times and poor handling conditions often result in strawberries with short shelf life and poor overall quality upon arrival at the retail store and consumer homes. The objectives of this study were to: 1) evaluate the environmental conditions during the whole distribution chain that comprises the time 'Albion' strawberries were harvested and delivered to the retail store and the impact on fruit quality; 2) evaluate the impact of steady optimum temperature against fluctuating temperatures encountered during field trials on the quality of 'Albion' strawberries; and 3) evaluate the effect of five different constant temperatures (1, 6, 10, 15, and 21°C) on the quality of 'Albion' strawberries harvested three-quarters or full red. For the first study, two shipments of strawberries were monitored from California to Georgia. The strawberries were either kept in a cold room in California at constant temperature or shipped through the entire strawberry distribution chain. Strawberries were evaluated in the field, after pre-cooling, at the distribution center (DC), and at the store for appearance, weight loss, incidence of bruising and decay, and soluble solids content (SSC). Transit times were found to vary

between about 7 and 9 days, with temperatures ranging from 0 to 30°C and 34 to 87% RH. Strawberry quality upon arrival at the DC was unacceptable due to poor appearance. Weight loss and incidence of bruising and decay increased during transit, while appearance ratings and SSC decreased. Bruised and decayed fruit were the major causes of rejection at the DC and at the stores, affecting 77.0 and 28.0% of the fruit, respectively. Strawberries kept at constant temperature fared better in quality than strawberries that were shipped. Long transit times and inadequate temperatures shortened the shelf life of the strawberries and contributed to poor fruit quality.

The second study was designed to validate the results obtained from field trials by simulating the entire handling process using additional sensory and compositional quality evaluations. Strawberries were stored under steady optimum temperature conditions (control) or under simulated handling conditions (fluctuating temperature) similar to those encountered during field trials. Strawberries from the fluctuating treatment had lower acidity, SSC, sugar, ascorbic acid (AA), anthocyanins, and phenolic contents compared to fruit from the control treatment. Results from the third study, in which strawberries were stored at different constant temperatures, showed that storage at 21°C resulted in fruit with poor quality and very short shelf life (2 to 3 days) while storage at 1°C resulted in fruit with best overall quality and longer shelf life (5 days). Overall, results from this study showed that reducing delays to cooling, shortening transit times, and keeping strawberries at constant low temperatures during the entire distribution chain would contribute to a fruit with better quality and longer shelf life. Such actions would also help to reduce economic losses by lessening the amount of fruit normally discarded as well as reducing waste of natural resources.

CHAPTER 1
INTRODUCTION

The most common strawberry species grown commercially, *Fragaria ananassa*, has its roots in North and South America. Descendants of *Fragaria virginiana* and *Fragaria chiloensis* were crossbred to produce larger and tastier fruit. Today, strawberry fruit are found growing on almost every continent in various soil and climate conditions due to years of cross breeding and adaptation (Morris and Sistrunk, 1991).

The United States is currently the major strawberry producer in the world (FAO, 2007). Most of the production occurs in California where 90% of the U.S. strawberries are grown, with Florida coming in second with only 7% of the strawberry production (Perez and Pollack, 2009). In the United States, strawberries are harvested throughout the year; in Florida from November to April and in California from April through early winter and at a smaller scale throughout the rest of the year (Bertelsen et al., 1995). A typical postharvest handling process for strawberry involves several steps: harvesting, sorting, packing, field stacking and palletizing, transporting by truck to the grower main facility, pre-cooling, storing at the grower, loading into trucks, shipping, unloading at terminal market or distribution center, and finally arriving at the retail store (Kader, 2002). A major portion of the postharvest life of strawberries is wasted during transit from the field to the store (Kader, 2002) leaving very often little time for storage at home. Strawberries are among the fruits most often discarded at the store level especially due to temperature abuse (Nunes et al., 2009).

When strawberries are stored under optimum temperature and humidity conditions, at 0°C and 90-95% RH, the typical shelf life is 7-10 days (Kader, 2002). It is however, crucial to cool the fruit immediately after harvest and to maintain as steady optimum temperature with the least fluctuation as possible since deviations from the optimum temperature often result in degradation of the quality and reduce the shelf life of strawberry fruit (Nunes et al., 1995a; Nunes et al., 2003).

Several sensory attributes are important contributors to the overall quality of strawberry such as color, texture, and flavor. After harvest, overall quality of strawberry deteriorates very fast with temperature having the greatest impact on the quality and shelf life of the fruit. In general, as temperature increases the quality and shelf life of the fruit are reduced. For example, when strawberries are stored for 8 days at 1°C at 90-95% RH, color attributes such as lightness, hue angle, and chroma value decrease as the fruit become less light, less red and more brownish (Nunes et al., 2006). Besides, weight loss tends to increase during storage causing shriveling and overall strawberry quality deterioration (Nunes and Emond, 2007). Hence, the relative humidity (RH) should also be taken into consideration to prevent shriveling caused by water loss (Shewfelt, 1992; Goulart, 1993). Strawberries are still prone to fungal decay especially if stored at 20°C (Shin et al., 2007). Firmness of strawberry fruit also decreases with time, especially under increasing temperature (Shin et al., 2008). Overall, exposure to high temperatures (above 0°C) during handling and storage hastens the degradation of the quality of strawberry fruit and reduces the shelf life.

Chemical composition also changes after harvest and, like sensory quality, tends to deteriorate faster when strawberry is exposed to temperatures above the optimum. For example, a slight decrease in acidity and soluble solids content (SSC) of strawberries was seen with increased storage temperature (Kalt et al., 1993; Ayala-Zavala et al., 2004). In terms of nutritional value, strawberries are considered a good source of antioxidants, namely phenolic compounds and vitamin C. However, phenolic (Shin et al., 2007) and ascorbic acid (AA) (Cordenunsi et al., 2003; Nunes et al., 2006) contents of the fruit are prone to degradation during postharvest life especially when fruit are exposed to temperatures above 0°C.

Due to lack of information regarding the environmental conditions and shipping times during real strawberry commercial operations from the field to the store, a study was devised to focus in detail on the quality-affecting factors which include time, temperature, and RH profiles normally encountered during the entire handling process. This study investigates the common causes for strawberry waste at the store level and the potential to extend shelf life and maintain postharvest quality of commercially grown ‘Albion’ strawberries. Field studies were first performed to evaluate the effects of real commercial operations on the quality of strawberries throughout the whole distribution chain; secondly, environmental conditions obtained from field studies were recreated in order to confirm the results obtained from field trials, and finally the effect of different constant storage temperatures on the quality and shelf life of ‘Albion’ strawberry was investigated.

CHAPTER 2
REVIEW OF LITERATURE

Origin and History

The history of the modern strawberry begins in the sixteenth and seventeenth centuries, following the discovery and colonization of North and South America when fleets from Portugal, England, Spain, Italy, Holland, and France returned from the New World with curious plants. Fletcher (1917) considered the origin of the strawberry mostly Pan-American since both the species from which most of the garden varieties of today have descended, *Fragaria virginiana* and *Fragaria chiloensis*, were brought to Europe from the New World.

The origin of the name Fragaria, from the Latin *Frago*, was attributed to the delicate and sweet flavor of the fruit. However, the word strawberry is peculiar to the English language since no other language refers to the fruit by a name that suggests straw (Wilhelm and Saga, 1974). The explanation for the word was attributed to the straw mulch used at that time to grow the strawberries, or to the fact that the children used to sell them in a bed of straw and they were known as the berries in straws (Wilhelm and Sagen, 1974).

The plant that became the progenitor of the modern strawberry appeared in Europe around mid eighteenth century, and was called the *Fragaria ananassa*, because its fragrance and flavor that resembled that of the pineapple fruit (Fletcher, 1917; Wilhelm and Saga, 1974). Therefore, the commercial cultivation of strawberries began only after 1800, and by then some different varieties of *Fragaria virginiana* started to be propagated (Fletcher, 1917). Around 1836, the list of different strawberry varieties had increased, and several other new varieties were developed in North America and

Europe from the wild varieties. Unlike other fruits, strawberry cultivation may be considered quite modern since the fruit has been grown in gardens from only less than 600 years, and was not cultivated commercially to any extent until the nineteenth century (Fletcher, 1917; Wilhelm and Sagen, 1974). Today, strawberries can be found growing on almost every continent and in nearly every country of the world, since they are adapted to a wide variety of soil and climate conditions (Morris and Sistrunk, 1991).

The United States is the world's largest producer of strawberries followed by other countries such as Spain, Turkey, Russia, South Korea, Japan, and Mexico (FAO, 2007). In the United States, California accounts for about 90% of the total production while Florida's production is about 7% (Perez and Pollack, 2009). Although production volume is small in Florida compared to California, strawberries are still the most important small fruit crop grown in Florida (Pollack and Perez, 2005). In Florida, strawberry harvest begins in mid November and continues until April, and, in California, harvest begins in April and continues all summer and into late fall or early winter (Bertelsen et al., 1995). There are many types of strawberry cultivars currently grown worldwide with each having their own advantage and created for that purpose or for a specific region. Two main types of strawberry fruit include the short-day and the day-neutral cultivars. Short-day cultivars depend on the length of day exposed and initiate flower buds if the day is less than 14 hours. Common short-day cultivars include: 'Camarosa,' Festival,' 'Elsanta,' 'Darselect,' 'Marmolada,' 'Addie,' 'Korona,' and 'Honeoye' (Zhao, 2007). Day-neutral cultivars initiate flower buds about every 6 weeks during the season regardless of the length of day (Zhao, 2007). These include: 'Diamante,' 'Albion,' 'Seascape,' and 'Selva' (Zhao, 2007). Major strawberry cultivars in California include: 'Albion,' Aromas,' ‘Camarosa,’ ‘Camino Real,’ ‘Diamente,’ and ‘Ventana’ (California Strawberry Commission, 2010). Major cultivars in Florida include: ‘Camarosa,’ ’Carmine,’ ‘Camino Real,’ ‘Gaviota,’ ‘Strawberry Festival,’ ‘Sweet Charlie,’ ‘Treasure,’ ‘Ventana,’ and ‘Winter Dawn’ (Peres et al., 2009).

Morphology and Physiology

Strawberry is neither a true berry nor a true fruit but an aggregate fruit with fleshy red receptacles (Zhao, 2007). Strawberries are dicotyledonous angiosperms with alternate leaves, stipulate and bisexual flowers, and belong to the rose family (Rosaceae). The hard seeds called achenes are fertilized ovules found only on the outside of the receptacle. Achenes are completely developed several days before the berry is mature and each achene contains a single seed (Avigdori-Avidov, 1986). Removal of the achenes results in abnormal fruit shape, and it has also been observed that the fleshy part of the berry is proportional to the number of achenes present in the fruit (Avigdori-Avidov, 1986).

The fleshy part of the berry, considered the edible part, includes the ripened receptacle/ ovary wall and the hard achenes (Lyle, 2006). The fruit is composed of five tissue zones: the epidermis, consisting of polygonal cells and stomata, and long, pointed, thick-walled hairs; the hypodermis, consisting of meristematic cells with no intercellular spaces; the cortex or true flesh, consisting of rounded cells with intercellular spaces; the bundle zone, comprising spiral and annular vessels; and the pith, consisting of thin-walled cells that often separate during the growth of the berry, leaving large cavities (Szczesniak and Smith, 1969). Embedded in the epidermis are the achenes, commonly known as seeds and recognized by their yellowish or brownish-green color and hard texture. The bundle zone is composed of the vascular system, xylem and phloem. Xylem are long hollow strands of vessel elements consisting of dead cells whose walls developed secondary thickenings in the form of rings, spirals, and nets. Xylem and phloem are used as water and dissolved mineral conducting tissues (Szczesniak and Smith, 1969; Salunkhe et al., 1991). The number of vascular bundles increases with the size of the fruit, and they also conduct water and nutrients from the stem through the central cylinder to the flesh and the seeds. Cells of the cortical layer have thinner walls than those of the pith, and increase in size during fruit growth about twice as fast as the pith cells. There is usually a gradient in cell size from smaller cells near the periphery to larger ones toward the inside (Avigdori-Avidov, 1986).

During development and ripening, strawberries undergo a series of changes in color, texture, flavor, and chemical composition until they reach the ripe stage. After the growth period of the fruit, three stages of development might be considered: maturation, comprising several changes that can occur between the cessation of growth and physiological maturity; ripening, changes that occur from the end of maturation period to the beginning of senescence, and finally senescence, when irreversible changes following ripening occur leading to the death of the fruit (Spayd et al., 1989).

Quality Characteristics

Strawberry is generally accepted to be a non-climacteric fruit and, as such, would not be expected to show an increased synthesis of ethylene or respond to exogenous ethylene. In fact, strawberry is considered to have a very low ethylene production rate (less than 0.1 $mL \cdot kg^{-1} h^{-1}$ at 20°C) characteristic of non-climacteric fruits (Kader, 2002). Therefore, like other non-climacteric fruits, strawberry should be harvested at or near the full red stage as it would not continue to ripen off the plant and immature fruit would have a poor eating quality (low sugar content, little juice and odd texture) (Kader, 1991; Nunes et al., 2006).

Quality of strawberries is based primarily on color, texture, and fruit flavor. Jamieson et al. (2000) suggested that color of the achenes, berry size, and berry glossiness would also be valuable quality attributes to consider. Visual appearance has been assumed to be a dominant aspect in the perception of the freshness of strawberries (Peneau et al., 2007). Besides visual attributes, sweetness and aroma were also considered by panelists as important quality attributes in the overall appreciation of the strawberry (Azodanlou et al., 2003).

During strawberry ripening on the plant, simple sugars that contribute to sweetness accumulate whereas organic acids and phenolic compounds that cause acidity and astringency decrease. An increase in aroma volatiles that yield the characteristic strawberry flavor is also observed during fruit ripening (Salunkhe et al., 1991). However, as strawberry matures, firmness of the fruit decreases. For example, Ménager et al. (2004) found that strawberry firmness decreased as the fruit color changed from white to half red and then appeared to stabilize from the three-quarter to the full and dark red stages.

Color of strawberry fruit is mainly due to three major pigments namely, anthocyanins, carotenoids, and chlorophyll (Woodward, 1972; Spayd and Morris, 1981; Gross, 1982; Given et al., 1988; Cheng and Breen, 1991). Anthocyanins are primarily located in the epidermal and hypodermic layers of the fruit and are important aesthetic components and natural indicators of fruit ripeness (Grisebach, 1982; Gross, 1987). The main anthocyanins of strawberry fruit are pelargonidin-3-glucoside and cyanidin-3-

glucoside (Bakker et al., 1994). Pelargonidin-3-glucoside comprises 80% of the total anthocyanin content in strawberry while cyanidin-3-glucoside is present in smaller amounts (Bakker et al., 1991). Cyanidin is responsible for the orange-red color of the fruit, while pelargonidin is responsible for the orange color (Mazza and Miniati, 1993). Differences in color among strawberry cultivars are due to different concentrations of these two pigments in the fruit. Also, patterns of color distribution have been related to the localization and quantity of the anthocyanin pigments in different tissues (Gross, 1987). Therefore, the external color of different strawberry cultivars might vary from a light orange-red to dark purple when the fruit are ripe. Internally, the color can vary from white centered fruit with a dark purple-red cortex to a uniform color. Color of a particular cultivar is also influenced by fruit maturity, physical damage, storage time and temperature after harvest. Other factors such as pH of the fruit, polyphenol oxidase (PPO) activity, acidity, ascorbic acid (AA), and phenolics also contribute to changes in the color of the fruit after harvest (Mazza and Miniati, 1993). As the strawberry fruit ripens anthocyanin content increases and chlorophyll content decreases (Woodward, 1972; Given et al., 1988; Montero et al., 1996; Ihl et al., 1999; Cordenunsi et al., 2002; Kosar et al., 2004; Nunes et al., 2006; Ferreyra et al., 2007). For example, an increase of about 31% in the total anthocyanin content of strawberry was observed as the fruit ripens and becomes redder (Nunes et al., 2006).

Strawberry sugar content is comprised by three major sugars such as sucrose, glucose and fructose, accounting for more than 99% of the total sugars in ripe fruit (Wrolstad and Shallenberger, 1981; Sturm et al., 2003). A red ripe strawberry typically contains 1.2% glucose, 1.5% fructose, and 0.6% sucrose (Forney and Breen, 1986).

However, a great variation in sugar content can be found due to environmental differences as well as cultivar characteristics (Wrolstad and Shallenberger, 1981; Haila et al., 1992; Shamaila et al., 1992).

Like sugars, organic acids are important flavor components, with the main acids in various strawberry cultivars being reported to be citric and malic (Reyes et al., 1982; Haila et al., 1992). Acids can directly affect fruit flavor, regulate cellular pH, and may influence the appearance of fruit pigments within the tissue (Manning, 1993). Of the total soluble compounds, acids are second to sugars, and in the strawberry, the non-volatile organic acids are quantitatively the most important in determining fruit acidity (Manning, 1993). Citric acid accounts for approximately 90% of the total acid content in strawberry fruit while the second most abundant is malic acid (Reyes et al., 1982; Haila et al., 1992; Sturm et al., 2003). Haila et al. (1992) reported a larger concentration of citric acid compared to malic acid in ripe strawberry fruit (0.76 and 0.40 g 100 g^{-1} of fruit fresh weight, respectively). Titratable acidity (TA) increases slightly to a maximum in mature green fruit and then declines rapidly in ripe or overripe fruit (Spayd and Morris, 1981; Montero et al., 1996; Moing et al., 2001; Sturm et al., 2003; Nunes et al., 2006). In general, a minimum of 7% SSC and a maximum of 0.8% TA are recommended for a strawberry fruit with acceptable flavor (Mitcham et al., 2007).

Strawberry is a very good source of vitamin C (ascorbic acid) since on average it contains 37 mg of vitamin C/100g of fruit (USDA, 2009). This means that with a daily supply of 100 g of strawberries (20 to 30 fruit), our vitamin C needs would be covered (Lundergan and Moore, 1975; McCance and Widdowson, 1978). During development and ripening, AA content of strawberries increases (Spayd and Morris, 1981; Montero et al., 1996; Olsson et al., 2004; Cordenunsi et al., 2002, Nunes et al., 2006). For example, Lineberry and Burkhart (1942) reported that green strawberry has only 20% of the AA content found in ripe fruit. Furthermore, the outer layer of the strawberry fruit was reported to contain more AA than the inner layers, and fruit ripened in the shade had less AA than those exposed to sun light (Burkhart and Lineberry, 1942; Ezell et al., 1947; Bender, 1978).

Optimum Handling Conditions

Due to their delicate, perishable nature, and short shelf life, strawberries are amongst the fruits most often discarded at the store level mainly due to bad temperature management (Nunes et al., 2009). In addition, since the major portion of the postharvest life for strawberries is wasted during transit from the field to the store (Kader, 2002), little time is left for storage at home. A waste of fruit and assets is also a waste of resources and energy spent on the entire handling process. For example, the time and labor to harvest the fruit is wasted, packages that were used would be lost, and energy involved in cooling and transportation is wasted.

If stored under optimum condition (0°C and 90-95% RH), the typical shelf life for strawberries is 7-10 days (Kader, 2002). Storage at this temperature reduces the respiration rate of the fruit resulting in extended shelf life. When the temperature is raised from 0 to 10°C, the rate of deterioration increases by two- to four-folds (Mitchell et al., 1996) due to an increase in the respiration rate and consequent depletion of sugars and acids (Moraga et al., 2006). When stored at 0°C, respiration rate of the fruit is approximately 12-18 $CO_2 kg^{-1} h^{-1}$ (Hardenburg et al., 1986), yet as the temperature increases to 15°C respiration rate of the fruit drastically increases to 75mL $CO_2 kg^{-1} h^{-1}$ (Wills et al., 2007).

Delayed cooling after harvest also affects the quality and shelf life of strawberry. Therefore, strawberries should be cooled immediately after harvested within 2 or 3 hours after harvest (Nunes et al., 1995a; Nunes et al., 1995b; Mitchell et al., 1996; Nunes et al., 2005). Cooling after harvest can be separated into two processes: 1) rapid removal of field heat, bringing the fruit temperature to that which approaches the optimum storage temperature and, 2) maintenance of that temperature during storage and transport. Delays before cooling results in increased weight loss, deterioration of the characteristic bright red color, decreased firmness, soluble solids content (SSC), and AA content of strawberry fruit (Nunes et al., 1995a).

After pre-cooling, strawberries should be maintained at a optimum constant temperature (0°C) as fluctuating temperatures during handling have been shown to cause higher incidence of bruising, weight loss, and faster growth of fungal decay (Nunes et al., 2003). Even though fluctuating temperatures can negatively affect the quality of strawberries, exposure to optimal temperature for short periods of time is preferred over maintaining the fruit at higher temperatures. For example, re-cooling strawberry after exposure to a temperature abuse during transportation would still be more beneficial than not re-cooling at all (Emond et al., 2004).

Effects of Environmental Conditions on Quality

Temperature and relative humidity (RH) are the two characteristics of the postharvest environment that have the greatest impact on the storage life of strawberries. Good temperature management is the most important and simplest factor in delaying fruit deterioration. In addition, optimum temperature storage retards aging of the fruit due to ripening, softening, and textural and color changes, as well as slowing undesirable metabolic changes, moisture loss, and spoilage due to fungal invasion (Hardenburg et al., 1986). Therefore, exposure of strawberry to temperatures higher than 0°C can drastically reduce shelf life and alter the quality of the fruit.

Color

Color is one of the most important quality attributes of strawberries (Sistrunk and Morris, 1985) since minor changes in natural or characteristic color of the fruit are directly related to loss of quality. Loss of color may take place very rapidly due to the great instability of pelargonidin-3-glucoside, the principal pigment of strawberries (Sistrunk and Cash, 1970). Sistrunk and Morris (1978) attributed changes in color of strawberries mostly to storage time and temperature. In fact, the rate of color loss in strawberries can increase two to three times for each 5°C rise above 0°C, with the fruit becoming darker. The chroma of the fruit decreases with increasing storage time, and loss of brightness (decrease in L* value) can also be observed (Sistrunk and Moore, 1967; Collins and Perkins-Veazie, 1993). For example, lightness, hue angle, and chroma values were found to decrease in trend when strawberries were stored for 8 days at 1°C at 90-95% RH (Nunes et al., 2006). In fact, Peneau et al. (2007) reported that in a sensory study panelists agreed that strawberries stored for 8 days at 0°C lost noticeable shininess. The calyx of the strawberries usually loses water and darkens during storage regardless of the storage temperature, and some browning can occur, especially in the crown of the calyx at the point of the pedicel attachment (Collins and Perkins-Veazie, 1993). Kalt et al. (1993) harvested strawberries at different stages of color development and, after 8 days at 5, 10, 20 and 30°C, noticed that anthocyanin formation and changes in surface color of white-harvested strawberries were temperature and time dependent. At 5 or 10°C, an increase in anthocyanin content occurred, and at 20°C pigments accumulated rapidly, but at 30°C, anthocyanin synthesis was slower than at 20°C. After 8 days at 5 or 10°C, unripe strawberries were still not completely red, however full red berries were dark red showing an overripe appearance (Kalt et al., 1993). Furthermore, development of strawberry surface browning was attributed to anthocyanin degradation and oxidation of soluble phenolic compounds, caused by a possible increase in the PPO activity as a result of water loss (Nunes et al., 2005).

Firmness

Softening of strawberry is also one of the most important changes occurring during the postharvest period, and has a great effect on consumer acceptability. The size, shape, composition of the cells, the turgor pressure, and the water relations of the cells are factors that determine textural parameters of fresh fruits, of which the most important are hardness, firmness and crispness (Bartley and Knee, 1982; Jen, 1989). After harvest, firmness of strawberries decreases, with rate depending on storage time, temperature, and RH (Smith and Heinze, 1958; Sistrunk and Moore, 1967; Ourecky and Bourne, 1968; Bartley and Knee, 1982; Luoto, 1984; Collins and Perkins-Veazie, 1993). Sensory panelists detected a decrease in juiciness and firmness of strawberries stored for 8 days at 0°C (Peneau et al., 2007). Besides, when temperature increases, strawberry firmness generally tends to decrease as well. For example, Shin et al. (2008) showed that firmness of strawberries decreased faster at 10°C than at 3°C. Furthermore, after 3 days at 15°C, strawberries were softer, while fruit stored for 7 days at 0 and 5°C maintained an acceptable firmness (Nunes and Emond, 2002). Delays in pre-cooling also resulted in decreased strawberry fruit firmness (Nunes et al., 1995a) and, even if pre-cooled within 2 hours of harvest, storage for 7 days at 1°C still resulted in a decrease in firmness and overall visual quality of strawberry 'Camarosa' (Laurin et al., 2003). Similarly, firmness of 'Oso Grande,' 'Dover,' 'Toyonoka,' 'Campineiro,' and 'Mazi' decreased after 7 days at 6°C (Cordenunsi et al., 2003). However, another study showed that 'Seascape' strawberries stored for up to 9 days at 5°C had no noticeable decrease in firmness with the exception of a slight decrease in the visual quality (Gil et al., 2006). In fact, the decrease in firmness does not seem to be linear. For example, 'Prarajathan' strawberries stored at 0°C showed a steady decrease in firmness of about 3% every 4 days until day 12, but after day 12 a 10% decrease in firmness occurred (Hansawasdi et al., 2006). In another study, Garcia et al. (1996) reported that 'Tudla' strawberries stored at for 3 days 18°C showed a drop in firmness by day 2 and a larger drop by day 3 resulting in a drop of about 70% in the firmness of the fruit at harvest. Finally, when exposed to fluctuating temperatures during handling, strawberry softened faster than when held at constant temperatures (Nunes and Emond, 1999; Nunes et al., 2003).

Decay

Storage temperature has a significant effect on the development of decay. For example, when strawberries were stored at 18°C and 95% RH, fruit rot developed rapidly, with more than 35% of the fruit showing decay after 2 days (Takeda et al., 1990). Decay increased rapidly in strawberry stored at 10°C, particularly after 7 days of storage while fruit stored at 5°C had slight fungal decay after 13 days. Furthermore, fungal decay was the major cause of strawberry fruit deterioration after 3 days at 20°C, and after 4 days at 10°C (Shin et al. 2007). Similarly, after 6 days at 10°C ‘Camarosa’ strawberries showed signs of fungal infection (Hernandez-Munoz et al., 2008) and after 2 days at 4°C, 7% of the batches of ‘Kent’ strawberries showed fungal decay (Vachon et al., 2003).

Weight Loss

Loss of weight after harvest is a major cause of deterioration (Nunes and Emond, 2007). Strawberry contains on average 81% of their weight in the form of water (USDA, 2009), some of which may be rapidly lost by evaporation if the fruit are not maintained under optimum storage conditions. This loss of water from the fruit tissues is known as transpiration (Hardenburg et al., 1986). Although some weight loss is also due to loss of carbon in respiration, this is only a minor part of the total weight loss that can be observed during storage, particularly when fruit are stored under non-optimum temperatures. In fact, storage temperature has an important effect on the weight loss of strawberries which in turn might also be dependent upon cultivar. For example, Testoni et al. (1989) showed differences in weight loss during storage among 24 different strawberry cultivars. Weight losses ranged 5.2% to 8.8% in different strawberry cultivars stored for 10 days at temperatures between 2 and 4°C and 80-85% RH. Nunes et al. (1998) showed that weight loss of ‘Chandler’, ‘Oso Grande’, and ‘Sweet Charlie’ strawberry cultivars increased as temperature increased from 1 to 20°C. Similarly, weight loss of ‘Jewel’ strawberry kept for 12 days in 95% RH was on average about 0.5% higher at 3°C than at 10°C (Shin et al., 2008). Finally, a weight loss as high as 20% was reported for ‘Florida’ and ‘Holiday’ strawberry cultivars after storage for 10 days at 0°C and 90-95% RH (Krivorot and Dris, 2000). Water loss during storage not only results in loss of weight but also leads to fruit with poor appearance due to development of shriveling, dryness of the calyx, and possible darker red color. Fruit surface browning and reduction of bright red color during storage of strawberry fruit was attributed to a lower concentration of anthocyanin and a high PPO activity (Nunes et al., 2005).

Sugars

Sugars are also important components of strawberry fruit as they contribute to the flavor quality. In general, sugar content decreases as storage progresses and it is greatly influenced by the temperature. Although Cordenunsi et al. (2003) found that total soluble sugars increased in some strawberry varieties, this increase was believed to be due to cell-wall degradation since no starch was available for synthesis of sugar. Total soluble solid contents of ‘Chandler’ strawberries stored at 0, 5, and 10°C were steady until day 5 but afterwards decreased drastically (Ayala-Zavala et al., 2004). However, the drop in total soluble solids was the largest in strawberry stored at 10°C and the lowest in fruit stored at 0°C. Similar results were reported by Nunes et al. (2002) with strawberry stored for 2 weeks at 10°C showing the steeper reduction in SSC compared to fruit stored at 4°C. Shin et al. (2007) showed similar results in strawberries stored at 0.5, 10, and 20°C, with the greatest reduction in SSC occurring in fruit stored at 20°C compared to that stored at 0.5°C. Delays in pre-cooling and longer exposure to 30°C have been shown to also decrease SSC of strawberry (Nunes et al., 1995a). Decrease in sugars is believed to be due to the higher respiration rate at higher temperatures, leading to higher depletion of sugars (Ayala-Zavala et al., 2004).

Ascorbic Acid (AA)

In general, AA (vitamin C) degradation is very rapid after harvest, and increases as the storage time and temperature increase (Fennema, 1977; Fennema, 1985; Kays, 1991; Salunkhe et al., 1991). Water losses during storage also have a great influence on vitamin stability (Ezell and Wilcox, 1959; Fennema, 1977; Barth et al., 1990). Low temperatures and maintenance of high humidity during storage delay degradation of AA (Zepplin and Elvehjem, 1944; Nelson et al., 1977; Barth et al., 1990). For example, in strawberry fruit stored for 8 days at 1 or 10°C, or for 4 days at 20°C, weight loss and AA degradation increased as the storage temperature increased. Compared to storage at higher temperatures, shelf life was extended and loss of AA was reduced by an average of 7.5 folds when strawberries were held at 1°C during the postharvest period (Nunes et al. 1998). A decrease of 50% from the initial AA content was also seen when strawberries 'Oso Grande,' 'Dover,' 'Toyonoka,' 'Campineiro,' and 'Mazi' were stored for 6 days at 6°C (Cordenunsi et al., 2003) compared to a decrease of about 7% for strawberry 'Oso Grande' stored for 8 days at 1°C (Nunes et al., 2006). Shin et al. (2008) found that AA content of 'Jewel' strawberries remained steady for the first 9 days at 3 and 10°C but after that decreased rapidly. In addition, strawberries can lose their AA content very rapidly if bruising occurs. That is, as cell walls are damaged, the enzyme ascorbate oxidase, normally present in the cells, is released and oxidizes the vitamin (Nobile and Woodhill, 1981; Klein, 1987).

Phenolics

Total phenolics have shown to be an important component of strawberry. Phenolic compounds contribute to the color and flavor of the fruit and seem to also be highly correlated with the total antioxidant capacity (Wang and Lin, 2000) which in turn seems to inhibit human cancer cell growth (Zhang et al., 2008). Unfortunately, total phenolic content tends to decrease as strawberry ripens and senesces. For example, Shin et al. (2007) showed a decrease in total phenolic content of strawberry after the second day of storage at 0.5 and 10°C and after day 1 when fruit were stored at 20°C. In another study however, total phenolics were higher when strawberries were stored for 13 days at higher temperature (10°C) as opposed to storage at a lower temperature (0°C) (Ayala-Zavala et al., 2004).

Aroma

Aroma is also an important factor in the quality of the fruit and it is also affected by storage temperature. For example, strawberry fruit stored at 5 or 10°C generally produce higher levels of aroma volatiles compared to fruit stored at 0°C (Ayala-Zavala et al., 2004). However, loss of aroma was faster in 'Seascape' strawberry stored at temperatures higher than 0°C (Nunes and Emond, 2002). Besides, after 3 days at 5°C fermentative metabolites were found in the aroma profiles of 'Camarosa' strawberries (Pelayo-Zaldıvar et al., 2007). After 3 days at 22°C, the level of ethyl acetate measured in strawberry fruit was about three times the amount and ethanol was more than the double of that measured in fruit stored at 10°C (Almenar et al., 2007).

Relative Humidity (RH)

Relative humidity (RH) of the surrounding environment is also an important factor that should be controlled during storage of strawberries. Humidity and temperature together are particularly critical in minimizing the difference in water vapor pressure between product and environment (Kays, 1991). The RH of the surrounding environment should be maintained at a level that minimizes the water vapor pressure deficit. Therefore, when RH is too low, transpiration is enhanced, resulting in loss of moisture and shriveling. The rate of fruit transpiration can be reduced by raising the RH, by lowering the air temperature, by minimizing the difference between the air temperature and the fruit temperature, by reducing air movement, and by protective packaging (Hardenburg et al., 1986). As water evaporates from the fruit tissue, turgor pressure decreases and the cells begin to shrink and collapse (Shewfelt, 1992; Goulart, 1993). The use of plastic packages such as clamshells can create a higher RH in the environment, avoiding loss of water during postharvest handling (Miller et al., 1993; Shewfelt, 1992; Collins and Perkins-Veazie, 1993). For example, Collins and Perkins-Veazie (1993) stored strawberries either in plastic boxes with plastic vented lids or in boxes with polyethylene wrap covers and warmed them up to 25°C for 8 hours. After warming up and before storage at 1 or 5°C, strawberry weight loss was greater in boxes with plastic vented lids than in boxes with polyethylene wraps (0.5 and 0.08% respectively). After 15 days of storage, fruit stored in boxes with plastic lids had about 4% weight loss while those packed in polyethylene had only about 1% weight loss. Kenny (1979) reported that wrapping strawberries with PVC film reduced weight loss from 2 to 5% during storage. Also, Aharoni and Barkai-Golan (1987) showed that packaging of strawberries with PVC wraps resulted in a marked reduction in moisture loss from the fruit as compared with unwrapped fruit. However, condensation can occur within the package when warm berries are covered and placed in a cold environment. This frequently occurs, since fruit temperature can decrease and increase several times during commercial handling (Goulart, 1993). Very high RH, as well as condensation on the berry surface can promote the development of decay by pathogenic organisms (Mitchell et al., 1996). Therefore, in order to avoid water loss as well as condensation, the RH of the storage environment for strawberries should be maintained in a range of 90 to 95%. In addition, strawberries should be cooled prior to packaging and fluctuations in the storage temperature should be prevented, because of the danger of condensation of moisture on the fruit favoring the growth of surface mold and development of decay (Mitchell, 1996; Boyette et al., 1989; Hardenburg et al., 1986; Goulart, 1993).

Research Objectives

The objectives of this study were: 1) evaluate the environmental conditions during the whole distribution chain that comprises the time ‘Albion’ strawberries were harvested and delivered to the retail store and the impact on fruit quality; 2) evaluate the impact of steady optimum temperature against fluctuating temperatures encountered during field trials on the quality of ‘Albion’ strawberries; and 3) evaluate the effect of five different constant temperatures (1, 6, 10, 15, and 21°C) on the quality of ‘Albion’ strawberries harvested three-quarters or full red.

CHAPTER 3
IMPACT OF ENVIRONMENTAL CONDITIONS DURING DISTRIBUTION ON THE QUALITY OF 'ALBION' STRAWBERRY FRUIT: FIELD TRIALS

Introduction

Quality of strawberries is based primarily on color, texture and fruit flavor. For best eating quality, strawberries should be harvested at or near the full ripe stage as immature fruit have poor eating quality (i.e., low sugars, little juice, odd texture) (Kader 1991; Nunes et al., 2006). However, firm ripe strawberries are fragile and thus very susceptible to bruising and decay. The quality of strawberries available at the retail store depends not only on the initial quality of the fruit at harvest but also on the way it was handled from the field to the store, with the length of time and environmental conditions (i.e., temperature and humidity) during handling and distribution having a significant impact on quality and shelf life.

Strawberries may experience a long handling process from the harvest to the store and thus there are many points in which the fruit can be exposed to abuse temperatures. A typical strawberry handling process involves: harvesting, sorting, packing, palletizing, transporting from the field to be pre-cooler, pre-cooling and storing under refrigerated conditions, shipping to the distribution center (DC) and transportation from the DC to the store, and finally displaying in the store until purchased by the consumer. Delays before cooling, inadequate pre-cooling and abuse/fluctuating temperatures during storage and distribution simultaneously with long transit times can significantly shorten the shelf life of strawberry. For example, delaying cooling has been shown to decrease the quality of the strawberry fruit with increased losses of AA, soluble solids, fructose, glucose and sucrose (Nunes et al., 1995a). When the temperature of the fruit is raised from 0 to 10°C, the rate of deterioration increased by two- to four-fold, and when strawberries were held at 29.4°C for different periods after harvest before pre-cooling a very rapid reduction in the amount of marketable fruit was observed (Mitchell et al., 1996). Therefore, in order to reduce decay and loss of quality during storage, strawberries should be pre-cooled immediately after harvest or not more than 2 or 3 hours after harvest (Nunes et al., 1995a, b; Mitchell et al., 1996; Nunes et al., 2005). In addition, prompt cooling reduced incidence of decay (*Botrytis cinerea* and *Rhizopus stolonifer*) by 25% and severity by about 24% (Nunes et al., 2005).

Fluctuating temperatures commonly encountered during distribution may also be detrimental to strawberry quality. For example, Nunes and Emond (1999) showed that strawberries stored in fluctuating temperatures had higher weight loss and pH, and lower firmness and glucose content than those stored at constant temperature. In addition, temperature fluctuations during handling can result in water condensation on commodity surfaces, potentially causing increases in the development of decay by fungal and bacterial pathogens. In summary, since strawberries are not sensitive to low temperatures, they should be pre-cooled and maintained at a constant temperature around 0°C in order to retain maximum acceptable quality and shelf life (Ayala-Zavala et al., 2004). Storage temperatures higher than 0°C greatly reduce postharvest life and even at the optimum storage temperature, the postharvest life of strawberries can be as short as 5 to 7 days (Hardenburg et al., 1986).

Poor temperature management and long transit times inevitably occur in commercial handling and reduce the quality and maximum potential shelf life of strawberries. Since there is a lack of information on the actual commercial operations and transit times as well as temperatures and humidity registered from the field to the retail store, the current study was designed to evaluate the whole distribution chain that comprises the time strawberries are harvested and delivered to the retail store and the impact on the quality of the fruit.

Materials and Methods

Fruit Selection and Instrumentation

‘Albion’ strawberries were harvested twice from the same commercial field in California, USA on September and October 2008. Strawberries were commercially hand-picked, placed inside clear plastic clamshells, and then inside cardboard flats (each flat accommodates 8 clamshells containing 454g of fruit each; approximately 20 to 22 fruit per clamshell). The flats were then assembled to form a pallet which contained 18 rows of 6 flats per row. For each field trial/harvest two pallets of strawberries were monitored. From each pallet, 9 flats of strawberries were identified and from the 9 flats, 27 clamshells of strawberries (3 clamshells per flat) were used for non-destructive quality evaluations. The remaining clamshells in a flat (5 clamshells per flat) were used for destructive quality evaluation, and for temperature and humidity monitoring. A total of 144 clamshells from the two pallets (54 clamshells for non-destructive and 90 for destructive) were used for each field trial.

After the fruit were selected and quality evaluated, a total of 18 temperature and humidity battery-powered data loggers (Hobo® U10 Temp/RH data logger, Onset Computer Corporation, Pocasset, MA, USA) were placed inside the clamshells for temperature and humidity monitoring (9 data loggers per pallet). The pallets were then assembled with the flats containing the selected fruit being placed in rows 14, 15 and 16 (3 flats per row). The pallets were then removed from the field within approximately 5 hours after harvest and brought to the cooling facilities. The trip from the field to the warehouse was approximately 30 min, after which the fruit were forced-air cooled for one hour.

Handling

After pre-cooling, the strawberries were stored in a cold room (~1°C) at the grower before being loaded into the distribution truck. From the 18 flats of strawberries initially selected, 6 flats (3 flats from each pallet) were left at the grower and kept under continuous cold storage (steady) throughout the whole distribution period. The remaining 12 flats were kept in the original pallets, loaded inside a refrigerated truck and shipped to a distribution center (DC) in Georgia, USA. Six of the flats were then collected from the DC for quality evaluation while the remaining 6 flats were shipped to a store in Georgia, USA and were collected upon arrival for quality evaluation.

Quality Evaluation

Due to the limitations of using sophisticated analytical techniques or equipment when working in an open field, simple procedures were chosen and used to evaluate the quality of strawberry. Thus, subjective quality evaluations such as appearance of the fruit, incidence of bruising and decay, and non-subjective evaluations such as weight loss and soluble solids content (SSC) where used as basic quality evaluation procedures. Evaluations were performed initially in the field, just after the fruit were harvested, after pre-cooling, upon arrival at the DC and upon arrival at the store. For non-destructive quality evaluations (weight, appearance, bruise and decay) the same fruit were used throughout the study (a total of 54 clamshells). For destructive analysis (evaluation of SSC) the remaining clamshells in the cardboard flat were used (90 clamshells). For the second harvest, due to limitations at the grower, quality of the fruit kept under steady conditions at the grower was evaluated right after harvest (initial) and after pre-cooling only.

Visual Quality

Overall appearance of the fruit such as freshness, color and texture was determined subjectively using a 1 to 5 visual rating scale where, 5 = excellent quality, fresh from the field and 1 = very poor quality, not acceptable for sale or consumption (Table 3-1). A score of 3 was considered the limit of acceptability before strawberry becomes unmarketable.

Incidence of Bruising and Decay

Incidence of bruising and decay was recorded by counting the number of strawberries in each clamshell with the presence of any (i.e., small or large) noticeable sign of decay or bruising. The percentage of fruit showing bruising or decay was then calculated based on the total number of fruit in each clamshell.

Weight Loss

Weight of each individual clamshell containing on average 20 strawberries each was measured using a precision balance with an accuracy of ±0.1 g (Mettler Toledo Model PL 1501-S, Mettler Toledo GmbH Laboratory and Weighing Technologies, Switzerland). Weight loss was then calculated from the weight of each clamshell measured initially and after every evaluation step (after pre-cooling, DC and store). Concentrations of SSC were expressed in terms of dry weight in order to show the differences between treatments that might be obscured by differences in water content. The following formula was used for water loss corrections: [chemical component (fresh weight) × 100 g / 4.8 g (strawberry average dry weight) + weight loss during storage (g)].

Soluble Solids Content (SSC)

Ten strawberries per evaluation time per treatment were hand squeezed inside a plastic bag and the juice extracted by filtering through a cheesecloth. The SSC was then determined by placing two drops of juice on the prism of a handlheld refractometer (r^2 mini handheld refractometer, Reichert Analytical Instruments, Depew, NY, USA). The SSC of strawberry was expressed in terms of fresh and dry weight.

Statistical Analysis

There were a total of two pallets per field trial/harvest containing 9 cardboard flats of strawberries each (total of 18 flats of strawberries per field trial/harvest). Each flat had 8 clamshells and each clamshell had approximately 20 to 22 fruit (total of 144 clamshells). Two temperature treatments (steady and fluctuating) were applied to the 18 flats of strawberries: 6 flats were used for the steady temperature treatment (left at the grower); 12 flats were used for the fluctuating temperature treatment (6 shipped to the DC and 6 shipped to the store). Quality evaluations were performed initially (right after harvest), after pre-cooling, at the DC and at the store). Field trials were repeated twice (first and second harvest). The analysis of variance was performed using the Statistical Analysis System 9.1 computer package (SAS Institute, Inc., Cary, N.C.). Data from the two field trials/harvests were analyzed separately as initial statistical analysis showed significant differences between harvests for most of the factors evaluated. However, no significant differences were obtained for the two pallets therefore data from the two different pallets was combined and analyzed simultaneously. Due to difficulties in obtaining enough data from the second field trial/harvest for a complete statistical analysis, only the LSD values for the first harvest are shown. Significant differences among the treatments (steady and shipped) were detected using the least significant difference (LSD) test at the 5% level of significance.

Results and Discussion

Handling Operations

Strawberries from the first harvest were removed from the field within 5 hours of harvest and pre-cooled for 2 hours whereas fruit from the second harvest were left in the field for 6 hours and upon arrival at the cooling facilities pre-cooled for 1 hour (Table 3-2). After pre-cooling, strawberries were kept in a refrigerated room during 41 or 24 hours for the first and second harvest, respectively, and then loaded into refrigerated trucks and shipped to the DC in Georgia. The transit times from the grower in California to the DC in Georgia were 115 and 106 hours for the first and second harvest, respectively. Upon arrival at the DC, strawberries were stored in a refrigerated room for 41 and 13 hours for the first and second harvest, respectively. Later, the strawberries were shipped to a store in Georgia with transit times of 4 to 17 hours for the first and second harvest, respectively. Upon arrival at the store, they were kept in consumer displays for 4 and 5 hours for fruit from the first and second harvest, respectively (Table 3-2).

The time it took the fruit to travel from the field to the store was 212 hours (8.8 days) and 172 hours (7.2 days) for the first and second harvests, respectively. Overall, the handling time from the field to the store was 1.6 days longer for the first harvest compared to the second harvest. Strawberries from the first harvest spent longer times at the grower cold room, shipping to the DC, and storage at the DC than fruit from the second harvest, whereas fruit from the second harvest spent longer time in transit from the DC to the store than the first harvest (Table 3-2). The time difference between the two field trials/harvests, as well as the long transit times from the field to the store, were mostly due to logistic issues related to grower and retailer protocols for shipping, load acceptance, unloading and store delivery.

Overall, the time it took the fruit to arrive from the field to the store was too long for both harvests considering that the postharvest life of strawberry can be as short as 5 to 8 days, even if stored at optimum temperature (0°C) (Hardenburg et al., 1986; Mitcham 2004; Nunes 2008). In addition, long delays before pre-cooling (5 and 6 hours for the first and second harvests, respectively) might have also shortened the shelf life and resulted in a poor quality fruit upon arrival at the retail level. Several studies have shown that the longer the time before pre-cooling the shorter the shelf life of strawberries. Therefore, in order to reduce decay and loss of quality, strawberries should be pre-cooled immediately after harvest or not more than 2 to 3 hours after harvest (Nunes et al., 1995a, b; Mitchell et al., 1996; Nunes et al., 2005).

Temperature and Relative Humidity (RH) during Handling

Strawberries from both harvests were handled under a fluctuating temperature and RH regime (Table 3-2). Field temperatures were higher and RH lower during the second harvest (29.6°C; 33.8% RH) compared to the first harvest (24.9°C; 51.6% RH). During pre-cooling, temperatures were lower and RH higher for fruit from the first harvest compared to the second harvest. During storage at the grower, DC and store and during shipping, differences in temperature between the first and second harvest were smaller and ranged from approximately1.0 to 2.0°C. During storage and shipping, humidity levels also varied with a difference between harvests ranging from approximately 2.0 to 8.0%. For the first harvest, the highest temperature was measured during transport from the DC to the store and at the store and the highest RH was measured during transport from the DC to the store. For the second harvest, the highest temperature and RH was measured at the store. Strawberries that were left at the grower facilities under steady conditions were kept at 0.3 to 1.1°C and 77.7 to 80.9% RH for the entire length of the shipping and handling.

As mentioned above, exposure of strawberries for extended periods of time (i.e., more than 3 hours) at high field temperatures such as measured in this study (24.9 and 29.6°C for the first and second harvest, respectively) may have shorten the shelf life of the fruit. Besides the delays in pre-cooling, strawberries were afterward handled under fluctuating temperatures that ranged from approximately 1.0 to 4.0°C or from 0 to 5.0°C for the first and second harvest, respectively. Fluctuating temperatures during handling may cause moisture condensation on the fruit, which favors the growth of surface mold and development of decay (Boyette et al., 1989; Hardenburg et al., 1986). Further, exposure of strawberries to fluctuating temperatures may result in increased loss of quality. For example, strawberries exposed to fluctuating temperatures during handling were softer, had higher weight loss and lower vitamin C contents compared to fruit handled under constant temperatures (Nunes et al., 2003).

Weight Loss

For both harvests, strawberry weight loss increased during handling from the field to the store and also in fruit that was kept at the grower under steady conditions (Figure 3-1). However, strawberries kept under steady conditions at the grower had more weight loss than shipped fruit, most likely due to a combination of several factors such as, the high air circulation inside the cold room; the low RH of the room and also due to the fact that shipped pallets were, after pre-cooling, entirely covered with a plastic wrap (Tectrol System ®) whereas strawberry flats from the steady treatment were not wrapped. After pre-cooling, strawberries from the first and second harvest lost approximately 0.6 and 2.4% of their initial weight, respectively. Upon arrival at the store strawberry weight loss was approximately 2.0 and 4.0% for fruit from the first and second harvest, respectively. Overall, shipped strawberries from the second harvest had higher weight loss compared to those from the first harvest probably due to the lower RH levels measured for the second harvest mostly during delays before cooling, during pre-cooling, storage at DC and transport from DC to store (Table 3-2).

During handling from the field to the store 'Albion' strawberries lost 3.0 or 5.0% of its initial weight, for the first and second harvest, respectively. According to Robinson et al., (1975) who reported that 6.0% weight loss was the maximum acceptable for strawberry marketability, weight loss values obtained in this study would not be considered unacceptable. However, in a more recent study a weight loss of 2.5 to 3.0% in 'Seascape' strawberries resulted in softening of the flesh, darkening of the color, over ripeness, shriveling and dryness of the calyx and skin (Nunes and Emond 2007). Weight loss is highly correlated to loss of water and tends to increase as temperature increases and RH decreases. For example, when strawberries were dipped in calcium chloride coating solutions weight loss was reduced when coating decreased the water permeability (García et al., 1996).

Appearance

Appearance of the fruit deteriorated significantly during shipping or under steady temperature conditions (Figure 3-2). When evaluated at the DC level, appearance of shipped strawberries was already past the maximum acceptable levels (rating of 3). Shipped fruit from both harvests appeared dark red, overripe and the calyxes were dry and wilted when evaluated upon arrival at the DC or store. Strawberries maintained under steady conditions had significant different ratings than shipped fruit. Steady fruit had a slightly better quality appearance (higher scores) than shipped fruit with less wilting and brighter color at the time shipped fruit arrived at the DC but appearance also deteriorated at the time of arrival at the store.

Delayed cooling combined with high fluctuating temperatures during shipping have a significant impact on strawberry appearance, composition and eating quality. Strawberries exposed to adverse conditions become softer, shriveled, darker in color, and with lower levels of SSC, AA, and sugar when compared to strawberries that were promptly pre-cooled and kept at optimum constant temperatures (Nunes et al., 1995; Nunes 2008).

Incidence of Bruising and Decay

Strawberries from the second harvest showed a high percentage of bruising at harvest (8.8%) while fruit from the first harvest had no bruises (Figure 3-3). For both harvest, incidence of bruising increased significantly in shipped strawberries upon arrival at the DC and store. Upon arrival at the DC, 73.1 and 71.4% of the fruit from the first and second harvest, respectively, were bruised, and at the store the incidence of bruising increased to 76.8 and 73.8% for the first and second harvest, respectively.

Decay increased in strawberries during shipping but was much lower or nonexistent in fruit kept under steady conditions at the grower (Figure 3-4). Upon arrival at the DC, shipped fruit from the first harvest showed a 7.0% incidence of decay, whereas decay affected almost 20.0% of the fruit from the second harvest shipped to the DC. At the store, decay significantly increased, affecting 26.0 and 27.6% of the fruit from the first and second harvest, respectively.

During truck transportation, strawberry fruit most likely experienced shock and vibration, with fruit rubbing against each other and against the walls of the clamshells. Mechanical injuries such as punctures, bruises, or cuts tend to weaken the fruit structural integrity leading subsequently to infection of fungal growth. Mechanically damaged fruit exposed to high fluctuating temperatures will also tend to develop more decay during subsequent storage than intact fruit (Nunes et al., 2003, 2005).

Soluble Solids Content (SSC)

The water loss that occurred during handling of strawberry fruit tended to mask real losses of SSC expressed on a fresh weight basis; in some cases seeming to show no difference, or even greater retention of the SSC compared to the strawberry fruit at the time of harvest (Figure 3-5). Although it might be argued that the SSC values expressed on a fresh weight basis represent the actual concentrations that would be experienced by consumers, the data is also expressed on a dry weight basis in order to illustrate the actual losses that occurred in the SSC irrespective of the concentrating effect imposed by water loss. Therefore, compared to initial values at harvest SSC content of strawberry on a dry base weight decreased in shipped and steady fruit (Figure 3-5). Overall, the initial SSC of strawberry at the time of harvest was reduced by approximately 23.0% when the fruit arrived at the store.

Decrease in SSC of strawberries had been previously reported when strawberries were handled under high temperatures. Reduction in SSC in strawberries exposed to abuse temperatures is mostly due to the depletion of the sugars reserves that results from an increase in fruit respiration metabolism, which involves the consumption of simple sugars (Ayala-Zavala et al., 2004). Delayed pre-cooling also causes increased losses in SSC compared to fruit that were promptly pre-cooled (Nunes et al., 1995a).

Conclusions

During handling of strawberry fruit from the field to the store, proper temperature management, fruit ripeness stage, and initial quality as well as weather conditions at the time of harvest, should all be taken into consideration, as abuse and/or fluctuating temperatures that can be encountered during normal handling operations may result in important losses at the retail display level or in consumers' homes, depending on the type and condition of the fruit being transported. Results from this study showed that exposure to temperature and RH profiles encountered during real strawberry handling, from field to the store, resulted in deterioration of fruit quality due to increased weight loss and incidence of bruising and decay, and decreased fresh appearance and SSC. This study shows that delays before cooling combined with long transit times and fluctuating temperatures encountered during handling of strawberry fruit from the field to the store contributed to poor quality and to rejection of loads of strawberry at the DC and store level.

Table 3-1. Visual quality rating and descriptors for strawberry.

5.0	4.5	4.0	3.5	3.0[a]	2.5	2.0	1.5	1.0
90% red; bright, glossy; calyx stiff, green; no shriveling or bruising; fruit appears very fresh (excellent)	95% red; slightly less bright and glossy; calyx green but slightly less stiff; no shriveling (very good)	Full red; less bright and less glossy; calyx green but slightly less stiff; minor signs of shriveling (good)	Full red; less bright and less glossy; calyx less fresh; signs of dryness may be noticeable (good to acceptable)	Full to dark red; slight loss of brightness and gloss; calyx may appear dry and wilted; isolated areas of dryness; soft spots (acceptable)	Full dark red; moderate loss of gloss; calyx appears wilted, dry; moderate shriveling, dryness; soft spots (acceptable to poor)	Very dark red; dull, not glossy; overripe, dry appearance; fruit are soft; calyx dry and yellowish or greenish-brown (poor)	Very dark, dull purplish color; fruit are soft, overripe and dry; some fruit may be leaky; calyx dry and wilted (poor to very poor)	Very dark brownish or purplish-red color; very dull, soft, dry or leaky, calyx is yellowish or brownish and dry (very poor)

[a]Rating of 3 is considered the limit of acceptability before strawberry becomes unmarketable.

Table 3-2. Time and average temperature and relative humidity (RH) measured during shipping and distribution of 'Albion' strawberries from the field to the store.

	First harvest time (hours elapsed)	Temperature (°C)	RH	Second harvest time (hours elapsed)	Temperature (°C)	RH
Harvest[a]	0	-	-	0	-	-
Harvest to pre-cool	5	24.9	51.6	6	29.6	33.8
Pre-cooling[b]	2 (7)	0.8	71.7	1 (7)	3.1	67.9
Cold room (grower)	41 (48)	1.1	77.7	24 (31)	0.3	80.9
Shipping to DC (truck)[c]	115 (163)	3.0	83.2	106 (137)	2.0	84.9
Storage DC	41 (204)	1.0	84.9	13 (150)	0.4	77.6
Transport from DC to store[d]	4 (208)	4.3	87.2	17 (167)	1.8	79.2
Store	4 (212)	3.7	82.6	5 (172)	4.5	85.4
Total time	212 (8.8 days)			172 (7.2 days)		

[a]Initial quality evaluation at harvest (0 hours = 0 days)
[b]Quality evaluated after pre-cooling (7 hours = 0.3 days)
[c]Quality evaluated upon arrival at the DC (first harvest: 163 hours, 6.8 days; second harvest: 137 hours, 5.7 days); DC = Distribution Center.
[d]Quality evaluated upon arrival at the store (first harvest: 212 hours, 8.8 days; second harvest: 172 hours, 7.2 days)

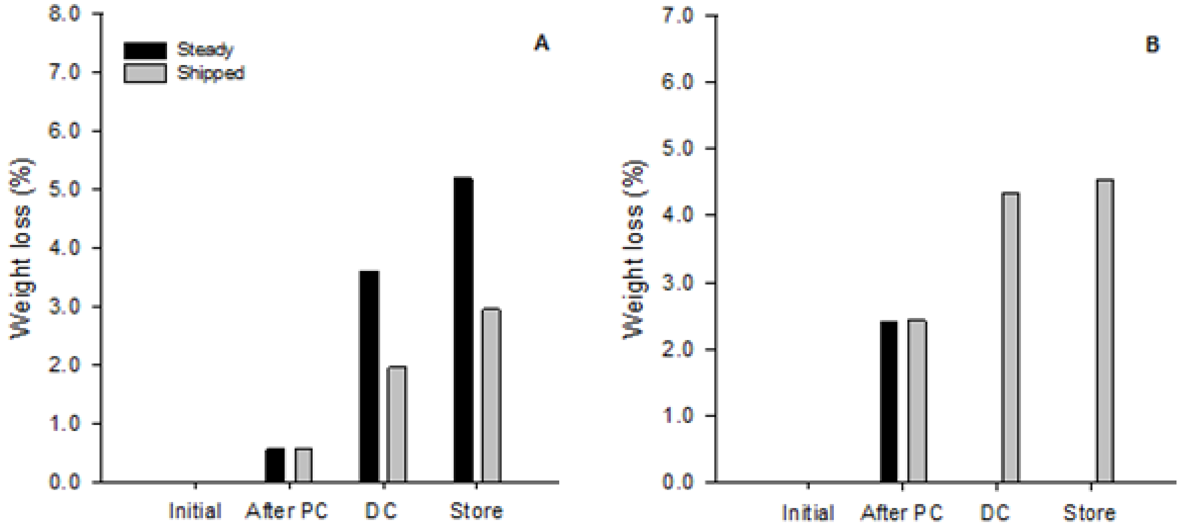

Figure 3-1. Weight loss of ‘Albion’ strawberries during shipping and distribution from the field to the store. A) First harvest with $LSD_{0.05}$=0.211. B) Second harvest.

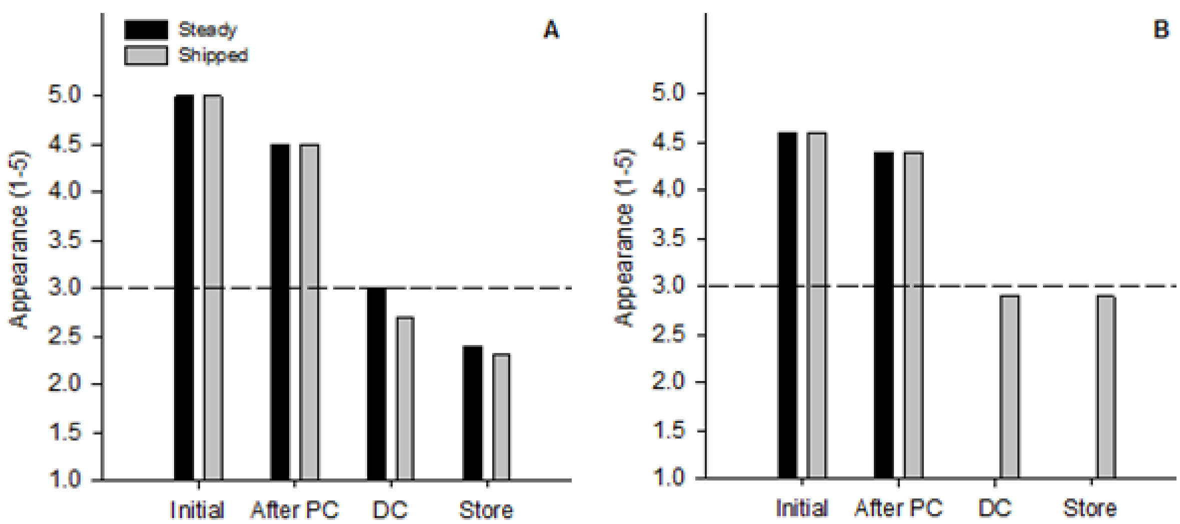

Figure 3-2. Appearance of ‘Albion’ strawberries during shipping and distribution from the field to the store. Dotted line (rating of 3) represents the maximum acceptable quality before the fruit becomes unsalable. A) First harvest with $LSD_{0.05}$ = 0.073. B) Second harvest.

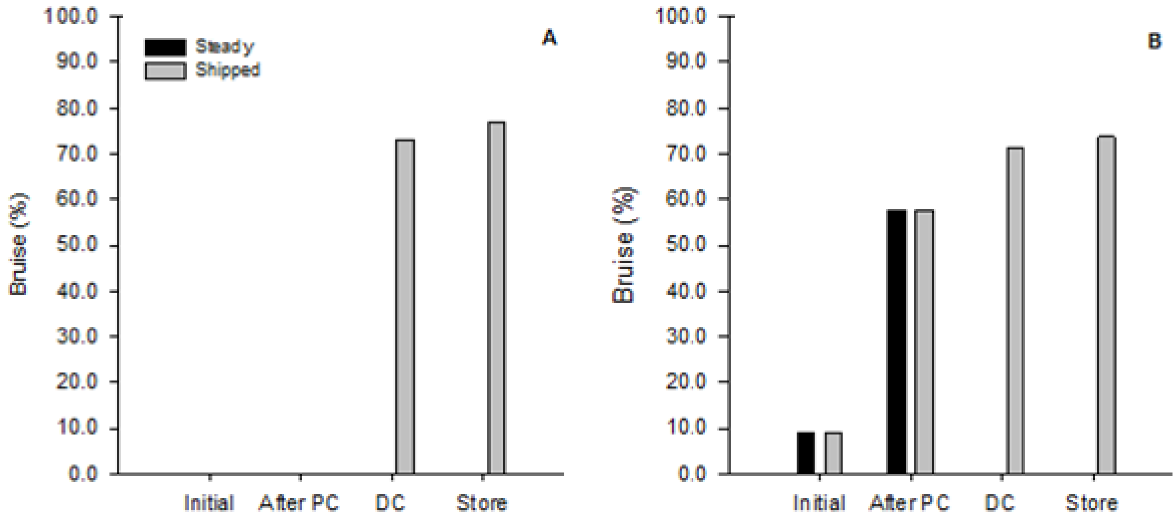

Figure 3-3. Incidence of bruise in ‘Albion’ strawberries from during distribution from the field to the store. A) First harvest with $LSD_{0.05}$=4.481. B) Second harvest.

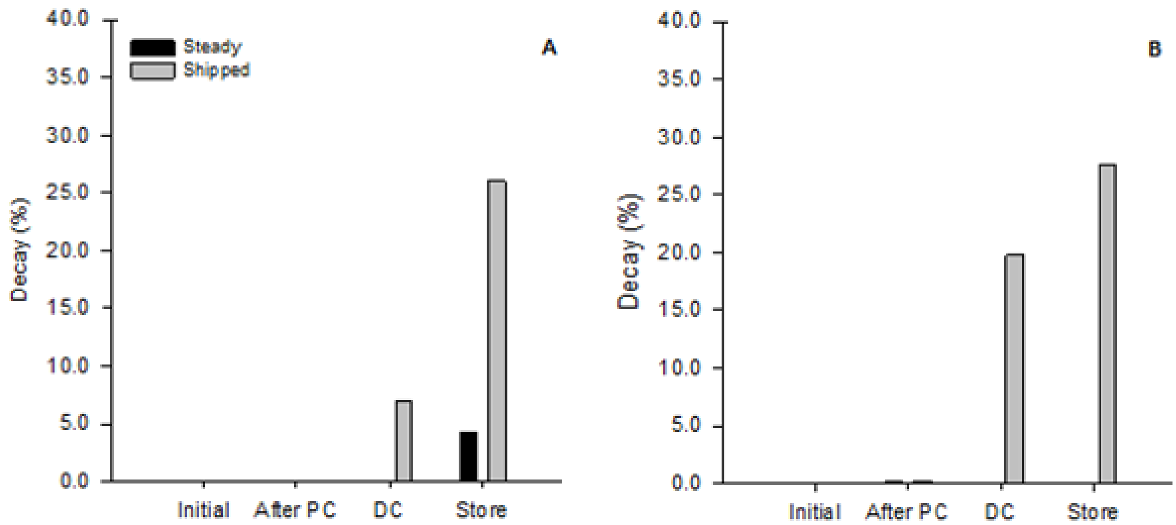

Figure 3-4. Incidence of decay in ‘Albion’ strawberries from during distribution from the field to the store. A) First harvest with $LSD_{0.05}$ = 5.312. B) Second harvest.

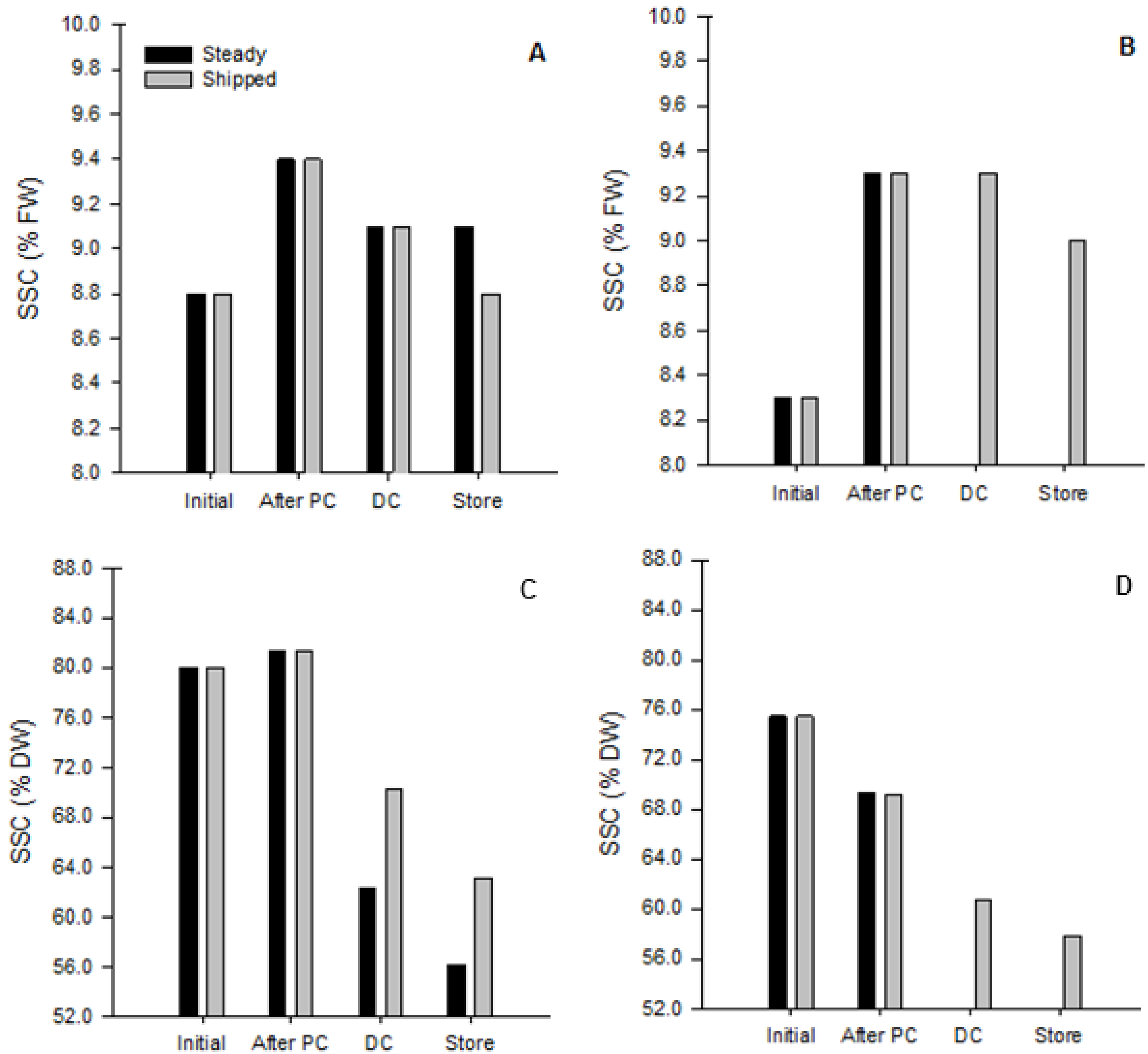

Figure 3-5. Soluble solids content (SSC) of 'Albion' strawberries measured during distribution from the field to the store. A) First harvest with SSC %FW $LSD_{0.05} = 0.098$. B) Second harvest. C) First Harvest with SSC %DW $LSD_{0.05} = 1.142$. D) Second harvest.

CHAPTER 4
IMPACT OF ENVIRONMENTAL CONDITIONS DURING DISTRIBUTION ON THE QUALITY OF ‘ALBION’ STRAWBERRY FRUIT: HANDLING SIMULATION

Introduction

Strawberries are highly perishable fruit and have a relative short shelf life. Therefore, time and temperature during handling from the field to the store are two of the most important factors affecting the final strawberry fruit quality.

Maintenance of a constant low temperature (0-1°C) is important during handling and storage of strawberries since respiration rates can be as high as 75mL CO_2 $kg^{-1}h^{-1}$ when the fruit are stored at 15°C (Wills et al., 2007). In addition, since strawberries have a maximum shelf life of only 7-10 days when kept under optimum storage conditions, transit time from the field to the store should be as fast as possible (Kader 2002). However, Kader (2002) showed that the major portion of the strawberry postharvest life is spent during transit from the field to the store. Results from field trials (Chapter 3) also indicated that delays before cooling combined with long transit times (approximately 7 to 9 days) and fluctuating temperatures encountered during handling of strawberry fruit from the field to the store contributed to poor quality and to rejection of loads of strawberry at the distribution center (DC) and store level. In fact, previous studies reported that strawberries are among the fruits most often discarded once they reach the store and on average 11.1% of the entire shipment of strawberries are found to be rejected by the store due to poor quality (Nunes et al., 2009).

Few studies have yet been performed to evaluate the effects of environmental conditions throughout the entire handling process, from the field to the store, on the quality of fruit and vegetables, and for strawberry in particular (Beaudry et al., 1998; Nunes et al., 2003; Emond et al., 2004; Nunes et al., 2006). The objective of this study was to validate the results obtained from field trials (Chapter 3) using a controlled environment and more accurate techniques of analysis. More specifically, evaluate the effects of handling and storage under controlled temperature conditions on the quality of ‘Albion’ strawberries, using more accurate techniques of analysis compared to basic techniques that were used in field trials. Strawberries were stored under steady optimum temperature conditions or under simulated handling conditions similar to those encountered during field trials, choosing the worst case scenario between the two field trials/harvests (Chapter 3). The visual, sensory, and compositional quality of the fruit were evaluated throughout the handling simulation process.

Materials and Methods

Plant Material and Handling Simulation

‘Albion’ strawberry fruit were obtained from a commercial field in Floral City, Florida. Fruit were removed from the field with minimal delay after harvest and transported to the laboratory in Gainesville, Florida within approximately 2 to 3 hours. A total of two harvests (simulations) were conducted. Strawberries for the first and second simulations were harvested during the 2009 spring season on March 16 and March 24, respectively. Upon arrival at the laboratory, strawberries were selected for uniformity of color and size, and freedom from defects. A total of 540 strawberry fruit were used for each simulation. These were divided into 270 strawberry fruit for each of the two treatments consisting of control (optimum temperature condition) and fluctuating temperatures (simulated handling conditions). Strawberry fruit were divided and kept in clamshells containing 10 fruit each. The clamshells containing the fruit were stored under the conditions of their corresponding treatments (Table 4-1). Five temperature and humidity controlled chambers (Forma Environmental Chambers Model 3940 Series, Thermo Electron Corporation, OH, USA) set at 1.0, 3.0, 4.0, 5.0 and 30.0°C with 85.0% relative humidity (RH) were used for the laboratory simulations. Time and temperatures used for the handling simulation were chosen based on the real time and temperature profiles measured during the field trials described in Chapter 3, choosing the worst case scenario between the two field trials/harvests. Control samples were kept at 1.0°C and 85.0RH. Quality evaluations were performed after each handling step for the control and fluctuating temperature samples.

Sensory Evaluation

The subjective quality attributes, color, firmness, shriveling, decay, taste, and aroma were evaluated either by visual, tactile, gustatory, or olfactory methods using 1-5 rating scales always by the same trained person (Table 4-2). A rating of 3 was considered to be the limit of acceptability before the fruit became unmarketable. For each temperature treatment, the same 30 strawberries were used for non-destructive quality evaluations (weight loss, color, firmness, shriveling and decay) at each handling step. For taste and aroma evaluations, 30 different strawberries per treatment were used at each handling step, due to the destructive nature of the evaluations. These 30 strawberry fruit were then used for the remaining destructive analysis.

Objective Color Measurements

Surface color measurements (L*a*b*) of 30 individual strawberries per treatment were taken with a reflectance colorimeter (Model CR-300, Minolta Co., Ltd., Osaka, Japan) on opposite sides of each fruit at the equatorial region for a total of two measurements per fruit. Color was recorded using the CIE-L*a*b* uniform color space (CIE-Lab), L* (lightness), a* (redness), and b* (yellowness) values. Numerical values of a* and b* were converted into hue angle ($\tan^{-1} b^*/a^*$) and chroma [$(a^{*2} + b^{*2})^{1/2}$] (Francis 1980).

Firmness Evaluation

Firmness of 30 individual strawberries per treatment was measured using a TA.XT plus Texture Analyzer (Texture Technologies Corp., NY, USA) fitted with a 7.9 mm diameter convex probe, and equipped with a 50-kg load cell. The probe was driven with a crosshead speed of 1 $mm \cdot sec^{-1}$. The force was recorded at 3.0 mm deformation. The measurements were made on the equatorial region of each fruit.

Compositional Analysis

Weight loss

Weight of strawberries was measured using a precision balance with an accuracy of ±0.015 g (Setra Model 5000L, Setra Systems, MA, USA). Weight loss was calculated from the weight of each subsample of 10 strawberries (3 subsamples per treatment) measured initially and after every simulation step. These 30 strawberries were the same used for the non-destructive sensory evaluations. Concentrations of chemical constituents were expressed in terms of dry weight in order to show the differences between treatments that might be obscured by differences in water content. The following formula was used for water loss corrections: [chemical component (fresh weight) × 100 g / 4.8 g (strawberry average dry weight) + weight loss during storage (g)].

pH, titratable acidity (TA), and soluble solids content (SSC)

Each individual replicated sample was thawed, and a 50-g aliquot of the tissue slurry was centrifuged at 6,000 × g for 20 min. The clear juice was decanted from the centrifuge tubes and the pH was determined using a pH meter (Accumet model 15, Fisher Scientific, Arvada, Colo., USA) that had been previously standardized to pH 4 and pH 7. Aliquots (6.00 g) of the juice were diluted with 50 mL distilled water and the titratable acidity (TA) determined by titration with 0.1 *N* NaOH to an end point of pH 8.1 with an automatic titrimeter (Titration Unit TitroLine easy, SCHOTT-GERÄTE Instruments GmbH, Germany). The results were converted to percent of citric acid [(mL NaOH $\times$ 0.1 N $\times$ 0.064 meq•6.00 g of juice^{-1}) $\times$ 100] and expressed in terms of dry weight. The soluble solids content (SSC) of the resulting clear juice samples was as measured with a digital refractometer (Palette PR-101, 0-45 °Brix, Atago Co. LTD, Tokyo, Japan). The SSC of strawberry was expressed in terms of dry weight.

Total sugar content

Total sugar analysis was conducted using a Hitachi HPLC system with a RI-refractive index detector and a 300 mm × 8 mm Shodex SP0810 column (Shodex, Colorado Springs, CO) with a SP-G guard column (2 mm x 4 mm). Isocratic solvent delivery of water was set at 1.0 mL/min. Sample injection volume was 5 µL. Several standards including sucrose, glucose, and fructose were used to identify sample peaks. After comparison of retention time with the standards, the peaks were identified. The amount of total sugar in strawberry was quantified using calibration curves obtained from different concentrations of sucrose and glucose standards. Three samples were used for each time with duplicate HPLC injections to be used as three replications. Total sugar content was expressed in g/100g dry weight.

Total ascorbic acid content

After weighing 2 g of homogenized strawberry tissue in a 50 mL tube, 20 mL metaphosphoric acid mixture (6% HPO_3 containing 2 *N* acetic acid) was added and mixed thoroughly. Samples were then filtered through a 0.22 μm filter prior to HPLC analysis. Ascorbic acid (AA) analysis was conducted using a Hitachi LaChromUltra UHPLC system with a diode array detector and a LaChromUltra C18 2μm column (2 × 50 mm) (Hitachi, Ltd., Tokyo, Japan). The analysis was performed under isocratic mode at a flow rate of 0.5 mL/min with a detection of 254 nm. Sample injection volume was 5 μL. Mobile phase was buffered potassium phosphate monobasic (KH_2PO_4, 0.5%, w/v) at pH 2.5 with metaphosphoric acid (HPO_3, 0.1%, w/v). Retention time of the AA peak was 0.35 minute. After comparison of retention time with the AA standard, the peak was identified. Amount of total ascorbic acid content in strawberry was quantified using calibration curves obtained from different concentrations of AA standards. Three replications were used for each storage time with duplicate HPLC injections. Total ascorbic acid content was expressed in mg/100g dry weight.

Total phenolic content

Total soluble phenolic compounds were measured using the Folin-Ciocalteu reagent (Folin and Ciocalteu 1927; Singleton and Rossi 1965). Aliquots (0.50 mL) of clear strawberry juice were diluted in 9.5mL deionized water, and to 1 mL of the resulting solution was added 5 mL of diluted (1:9) Folin-Ciocalteu reagent. Between 0.5 and 8 min after addition of the Folin-Ciocalteu reagent, 4 mL of sodium carbonate solution (0.075 g/mL) was added. After 1 h at 30°C plus 1 h in ice (0°C), the absorbance of the solution was measured at 760 nm. Gallic acid was used as the standard, and the concentration of total soluble phenolics was expressed as mg/100 g fruit dry weight.

Total anthocyanin content

Three replicate samples of 10 fruit per treatment were homogenized in a laboratory blender at high speed for 2 min. Aliquots (2.00 g) of homogenized strawberry fruit tissue were mixed in 18 mL of 0.5% (v/v) HCl in methanol and held for 1 hour at 4°C to extract the pigment. The flocculate was removed by filtering the extract through a single layer of facial tissue and absorbance of the resulting clear liquid containing the pigments was measured at 520 nm (maximum absorbance for anthocyanins). Pigment content was calculated using the following formula: A520 × dilution factor × [molecular weight (MW) of PGN/molar extinction coefficient] where MW of PGN = 433.2 and the molar extinction coefficient = 2.908 × 104. Results were expressed as mg PGN /100g dry weigh (PGN = pelargonidin-3-glucoside which is the major pigment in strawberry).

Taste Panel

Two taste panel sessions were performed on strawberries at the end of the simulation process, that is, after the store handling step, in order to evaluate consumer acceptability with strawberries at the store. The two sessions were conducted at the University of Florida's taste panel lab, which is equipped with 10 booths and with an average room temperature of 24°C. The first taste panel session included a total of 75 panelists for the evaluation of first simulation/harvest strawberries. The second taste panel session included total of 74 panelists for the evaluation of second simulation/harvest strawberries. CompuSense software (CompuSense 4.8.8, Inc., Ontario, Canada) was used to collect and perform the statistical analysis of the data.

A total of three strawberries in random order were presented to each panelist during the first taste panel session. Presented strawberries consisted of one whole strawberry from the control treatment (steady optimum temperature), a whole fruit from the fluctuating (handling simulation), and a fresh fruit harvested the same day the taste panel was performed. Each panelist was asked to rate (on scale 1-9; 1 = dislike extremely, 9 = like extremely) the following characteristics on each of the three strawberry samples presented to them: overall appearance, overall acceptability, firmness, strawberry flavor, and sweetness. Panelists were then asked to rank the samples in order of preference. Comments were allowed at the end.

During the second taste panel session, one additional question about the appearance of the strawberry calyx was added, and the fresh strawberry sample was removed from the protocol in order to allow the panelist to focus on evaluating any differences or similarities between strawberries from the control and fluctuating temperatures. Thus, a total of two strawberry treatments in random order were presented to each panelist. Presented strawberries consisted of one whole strawberry from the control and one whole strawberry from the fluctuating temperature treatments. Each panelist was asked to rate (on scale 1-9; 1 = dislike extremely, 9 = like extremely) the following characteristics on each of the two strawberry samples presented to them: overall appearance, appearance of the calyx (called ‘leaves’ on the form to ensure panelist understanding), overall acceptability, firmness, strawberry flavor, and sweetness. Panelists were then asked to choose the sample they preferred. Comments were allowed at the end.

Statistical Analysis

The analysis of variance was performed using the Statistical Analysis System 9.1 computer package (SAS Institute, Inc., Cary, N.C.). Data from the two simulation/harvests were analyzed separately as initial statistical analysis showed significant differences between harvests for most of the factors evaluated. Significant differences among the two temperature treatments (control and fluctuating) were detected using the least significant difference (LSD) test at the 5% level of significance.

Results and Discussion

Sensory Evaluation

Color

Although initial color of strawberries at harvest received higher ratings in fruit from the first simulation (fully light red) compared to fruit from the second simulation (3/4 colored to full red), color ratings increased throughout the handling simulation as the fruit color darkened, regardless the treatment and time (Figure 4-1). For both simulations, there was a significant difference between the color ratings of strawberries from the fluctuating and control treatments. That is, strawberries from the fluctuating treatment had higher color ratings (more dark red) than control strawberries, regardless the simulation/harvest. However, in the first simulation the increase in color ratings with time and temperature was more evident than in the second simulation. Rate of increase in strawberry color ratings was steeper after 5 hours (harvest to pre-cool), after 163 hours (shipping to DC), and after 208 hours (transport to DC to store) when compared to other handling steps. These steps with larger increase in color rating (darkening of the fruit) corresponded to the time strawberries were handled at temperatures above 3.0°C while the least increase in color ratings corresponded to the time the fruit were handled at 1°C. Higher handling temperatures most likely contributed to an increase in the color development rate resulting in darker red fruit. A previous study showed that the higher the exposure temperatures for strawberries the faster the decrease in the quality appearance ratings (Shin et al., 2007).

For both simulations there was a significant difference between the fluctuating treatment and the control treatment regarding the L*, hue and chroma values of strawberry (Figure 4-2). In general, strawberries from the control treatment had higher

L*, hue, and chroma values when compared to fruit from the fluctuating temperatures meaning that fruit handled under fluctuating temperatures were darker (lower L* value), more dark red (higher hue values) and less vivid (lower chroma values) than fruit kept constantly at 1°C. Although visually the color of strawberries from the first simulation/harvest darkened throughout (Figure 4-1), L* values decreased initially, but then showed a slight tendency to increase. On the other hand, L* values of fruit from the second simulation/harvest decreased and were lower after 212 hours (store) compared to at the time of harvest (Figure 4-2). Hue and chroma values also decreased during the simulation as the fruit color darkened and became less vivid. For example, chroma increased as time progressed till the strawberry becomes bright vivid red. Subsequently, chroma values dropped towards the end of the simulation due to development of darker color and browning. Similar results have been previously reported by Shin et al. (2007) in which strawberries exposed to 0.5°C had the highest L*, hue, and chroma values compared to fruit exposed to 20°C, for which color values decreased quickly after 4 days of storage.

Firmness

Firmness ratings were significant different between strawberries from the fluctuating and control treatments (Figure 4-3). Firmness ratings decreased during the simulation period for both control and fluctuating treatments as the fruit became softer. Firmness ratings for strawberries from the control treatment were higher (firmer fruit) compared to the fluctuating treatment, particularly for fruit from the second simulation/harvest. Softening may be mainly explained by the degradation of the fruit cell well (Hernández-Muñoz et al., 2006), which is in general faster when fruit are exposed to high temperatures. Differences in firmness could also be attributed to ripeness stage and quality of the fruit at harvest, cultivar variability, season of harvest and weather conditions. Control strawberries from the first and second simulation started to soften after 48 hours (cold room). This delay in softening underscored the importance of keeping the strawberries at optimum temperatures to delay the onset of softening. At the end of the second handling simulation, when strawberries arrived at the store, fruit from the control treatment were clearly firmer than the fruit from the fluctuating treatment. However, at the end of the simulation (store) only the fruit from the control treatment from the second simulation/harvest had acceptable firmness ratings (higher than 3).

Objective firmness measurements validated the subjective tactile evaluation, as firmness of the fruit decreased during the simulation, regardless of the treatment (Figure 4-3). Also, and similarly to the results obtained for subjective evaluation, firmness of strawberry from the control treatment was higher compared to the fluctuating treatment. Strawberries from the fluctuating treatment had lower firmness throughout most of the handling process indicating the advanced senescence of the fruit. A study done by Shin et al. (2008) reported similar results in that firmness of strawberries stored at higher temperature (10°C) decreased more than that of strawberries stored at lower temperature (3°C).

Shriveling

Shriveling of the strawberries worsened as time progressed regardless of the temperature treatment (Figure 4-4). Shriveling in strawberries from the second simulation/harvest was beyond the acceptability rating of 3 during the period the fruit left the cold room and were shipped to the DC (48 to 163 hours). In fruit from the first simulation, shriveling also increased during the same period of time, but was not objectionable (rating below 3). There was a significant difference between shriveling of fruit from the control treatment and the fluctuating treatment. Fruit from the control treatment appeared less shriveled than fruit from the fluctuating treatment, regardless of the simulation/harvest. Lower shriveling rates in fruit from the control treatment resulted from keeping the fruit at optimum constant temperature. Increase in shriveling ratings paralleled the increase in weight loss over time (Figure 4-7). That is, the higher the weight loss the more apparent the shriveling. In fact, fruit shriveling caused by rapid water loss was previously reported as a common problem during postharvest handling of strawberry (Kader, 2002).

Decay

Although decay ratings remained within acceptable levels (ratings below 1.5) throughout the simulation, fruit from the fluctuating treatment showed higher decay incidence than fruit from the control treatment (Figure 4-5). As time progressed the fruit became softer and decay started to develop particularly if fruit were exposed to higher temperatures during the handling simulation. At the end of the handling simulation, some of the fruit evaluated in this study would most likely be unmarketable at the store level. These signs of decay could be due to the late strawberry season at the time the two simulations were performed. Nevertheless, fruit from the fluctuating temperature received higher decay ratings than those handled under optimum constant temperature. Ayala-Zavala et al. (2004) also reported that after 13 days of storage fungal decay increased the fastest in strawberries stored at 10°C, slightly faster in fruit stored at 5°C, and the least in fruit stored at 0°C.

Taste, aroma, and taste panel

While taste of strawberry did not change during the first simulation, taste ratings in the second simulation showed a clearer trend in degradation of the quality of taste over time (Figure 4-6). Strawberries from the fluctuating treatment had lower taste ratings than the control yet differences in the taste of the fruit from the fluctuating treatment were not significantly different from the control strawberries. Taste of the strawberry was best at harvest and degraded as the fruit progressed through each handling step. Exposure of strawberries to higher temperatures during the fluctuating treatment hurried the senescence stage resulting in lower taste ratings than the strawberries of the control treatment. However, at the end of the handling simulation (store), the taste ratings from the control and fluctuating treatments were similar. Almenar et al. (2007) showed that during a 10-day period acetaldehyde, ethanol and ethyl acetate, which are the main volatiles responsible for off-flavors, increased significantly in strawberries stored at room temperature (22°C) compared to those stored under refrigerated conditions (10°C).

Aroma together with taste contributes to the characteristic flavor of the strawberry fruit. Aroma ratings showed the same trend as taste ratings but were higher than those obtained for taste. That is, taste quality seemed to deteriorate more than the aroma quality of the fruit (Figure 4-6). Overall, aroma ratings decreased as time progressed for the second simulation only while like taste there was no change in the aroma of the fruit from the first simulation. Constant optimum temperature delayed the degradation of aroma by 2 days for the control strawberries compared to the fruit from the fluctuating treatment.

No significant trend could be deduced from the taste panel sessions for most of the questions asked to determine the best strawberry sample. Although in the first taste panel session (first simulation/harvest) panelists showed a trend towards choosing the fluctuating over control strawberries, the differences between treatments were not significantly different (Table 4-3). Control and fluctuating treatments had no significant difference when looking at the overall appearance, overall acceptability, firmness, strawberry flavor, and sweetness. For the second simulation, the only response that was deemed significantly different between the fluctuating and control samples was the question on appearance of the calyxes, as panelists responded that they liked the calyxes on the control strawberries better than the fluctuating strawberries. The preference question from session two (second simulation/harvest) where panelists were to choose the strawberry they would most likely prefer (between control and fluctuating) was deemed not significant (Table 4-4). Overall, no significance between the strawberry samples from control and fluctuating temperatures was probably due to the advanced ripeness stage of the fruit from the late harvests used in this study, and most likely due to the adverse weather conditions experienced by the strawberry growers during this 2009 spring season. In fact, a study done by Shin et al. (2008) showed that strawberries harvested with red tips (more ripe) obtained lower overall quality ratings and were less firm than strawberries harvested with white tips (less ripe) after 12 days of storage at 3°C.

Compositional Analysis

The high levels of water loss observed in strawberries from the fluctuating treatments, tended to mask real losses on a fresh weight basis of some constituents - in some cases seeming to show no difference, or even greater retention of some constituents compared to the strawberries from the control treatments. Although it might be argued that the compositional values expressed on a fresh weight basis represent the actual concentrations that would be experienced by consumers, the compositional data is expressed on a dry weight basis in order to illustrate the actual losses that occurred in certain constituents irrespective of the concentrating effect imposed by water loss.

Weight loss

Weight loss increased during the handling simulation in all treatments (Figure 4-7). However, after 212 hours (store) strawberries from the control treatment had lost less weight (11.4 and 15.8% weight loss for the first and second simulations, respectively) than fruit from the fluctuating treatment (15.9 and 16.9% weight loss for the first and second simulation, respectively). According to Robinson et al. (1975) who reported that 6.0% weight loss was the maximum acceptable for strawberry marketability, weight loss values from this study would be considered unacceptable shortly after the shipping to the DC (between 48 and 163 hours). Differences in weight loss between strawberries from the fluctuating and the control treatments were significantly different for the first simulation, but not for the second simulation. Weight loss followed the expected trend of increasing as time progressed throughout the simulation. As time elapsed, weight loss continued to increase due to transpiration and respiration of the fruit (Hernández-Muñoz et al., 2006). Strawberries from the fluctuating treatment were exposed to higher temperatures, which caused an increase in fruit respiration and transpiration leading to more water loss. In another study, exposure of strawberries to higher temperatures has also been shown to be correlated with higher weight loss values (Shin et al., 2007). In fact, weight loss is highly correlated to loss of water and tends to increase as temperature increases and RH decreases. Weight loss during storage due to loss of water also results in deterioration in the visual appearance of the fruit as well as decrease in chemical compounds such as sugars, acids, and pigments. For example, weight loss of 2.5 to 3.0% in ‘Seascape’ strawberries resulted in softening of the flesh, darkening of the color, over ripeness, shriveling and dryness of the calyx and skin (Nunes and Emond, 2007). Weight loss caused by water loss also increased polyphenol oxidase (PPO) activity and possibly decreased the total anthocyanin and phenolics content in strawberries during storage at 1°C (Nunes et al., 2005).

pH, titratable acidity (TA), and soluble solids content (SSC)

Strawberry pH did not change significantly during the handling simulation for any of the temperature treatments (Figure 4-8). Differences in the pH of strawberries from the fluctuating treatment and control were significantly different only for the second simulation. Control and fluctuating strawberries showed no large pH differences after the simulation. Another study showed similar results, with strawberry pH being stable during storage at 0.5, 10 and 20°C (Shin et al., 2007).

Acidity decreased over time for strawberries, regardless of the treatment (Figure 4-8). However, differences in acidity between strawberries from the fluctuating and control treatments were significant only for the first simulation. Differences in acidity were not large between the control and fluctuating strawberries although acidity of fruit from the fluctuating treatment seemed to be lower than the control. Shin et al. (2007) also reported no significant differences in acidity of strawberries stored at 0.5, 10 and 20°C (Shin et al., 2007).

SSC of the strawberries decreased significantly as time progressed regardless of the temperature treatment (Figure 4-8). However, differences in the SSC of strawberries from the fluctuating and the control treatments were significant only for the first simulation. Fruit from the fluctuating treatment had lower SSC than the control, which was more evident in first simulation. The lower SSC can be attributed to the exposure of fruit from the fluctuating treatment to higher temperatures, which increased fruit respiration rate and sugar and acids depletion. Similar results were reported by Shin et al. (2007) in which SSC of strawberries was reduced when the fruit were stored at higher temperature (20°C) and was reasoned to be due to higher respiration rates at higher temperatures (Shin et al., 2007).

Total sugar content

Total sugar content of strawberries significantly decreased during the handling simulation, regardless of the treatment or simulation/harvest (Figure 4-9). However, in the first simulation, total sugar content of strawberries from the control treatment was significantly higher than that of fruit from the fluctuating treatment. In the second simulation, after 212 hours (store level) total sugar content of strawberries from the fluctuating treatment was significantly different from that of strawberries from the control treatment, but not as pronounced as the first simulation. Towards the end of the handling simulation, after 208 hours, total sugar content dropped drastically, regardless of the simulation or treatment, as strawberries became more senescent and decay incidence increased. By the end of the handling simulation (store level; 212 hours), the initial sugar content of the strawberries was reduced by an average of 61% for control and 64% for fluctuating treatments. The drastic decrease in total sugar content during the first hours that followed harvest (48 hours) might have resulted from the delays in pre-cooling the fruit, which most likely resulted in an increase in the respiration rate of the fruit and accelerated the consumption of sugars. In fact, in an earlier study by Nunes et al. (1995a), strawberries exposed to warm field temperatures (30°C) for 6 hours before pre-cooling had lower sugar content, namely glucose, sucrose and fructose, compared to fruit that were promptly pre-cooled after harvest.

Total ascorbic acid content

Ascorbic acid (AA) content decreased during the handling simulation, regardless of the treatment of simulation/harvest (Figure 4-10). However, in the first harvest only, AA content of strawberries from the fluctuating treatment decreased faster and was significantly lower than that of fruit from the control treatment until the time that corresponded to storage at the DC (204 hours after harvest). Afterwards, AA content of fruit from the control treatment decreased sharply to values similar to that of strawberries from the fluctuating temperature treatment. For strawberries from the second simulation, there was also a significant difference in the AA content of strawberries between the control and fluctuating treatments, but not as pronounced as the first simulation. In the first harvest/simulation, the initial AA content of the strawberries was, by the end of the simulation process (store level; 212 hours), reduced by approximately 60% and 63% in fruit from the control and fluctuating treatments, respectively, whereas in the second harvest/simulation the total ascorbic acid content of the fruit was reduced by approximately 63% for both the control and fluctuating treatments. Overall, exposure to higher temperatures during the fluctuating treatment, at least for the first harvest, caused a faster and larger reduction in the AA content of the fruit. Similar results were reported by Shin et al. (2007) where AA for strawberries was more stable during storage at 10°C while storage at 20°C resulted in a significantly greater decrease in AA of the fruit.

Total anthocyanin content

Total anthocyanin content of strawberries decreased as time progressed, regardless of the treatment (Figure 4-11). At the end of the handling simulation, there was a slight but significant difference in the total anthocyanin content between strawberries from the fluctuating and control treatments. Rates of decrease in anthocyanin for control and fluctuating treatments paralleled each other in the second harvest during the cold room to the DC time period. Since anthocyanins are the main type of pigment found in full red strawberries, the slight difference in the anthocyanin content of strawberries between the two treatments may have contributed to differences in the color of the fruit between the control and the fluctuating treatments (Figure 4-1 and 4-2). A study done by Nunes et al. (2005) found that the anthocyanin content in strawberries decreased when the fruit were stored for 8 days at 1°C and was reasoned to be due to an increase in polyphenol oxidase (PPO) activity as a result of water loss, which contributed to the development of strawberry surface browning.

Total phenolic content

Total phenolics content decreased during the handling simulation, regardless of the treatment (Figure 4-12). Differences in the total phenolic content of strawberries between the fluctuating and control treatments were significantly different for both simulations. However, the difference in the phenolic content between treatments was more evident in the first simulation than in the second, in which the differences were smaller. After the initial drop in the phenolic content after 7 hours (pre-cooling), the declining rate in the phenolic content remained constant. A similar trend was observed for strawberries that were harvested full red with no white tip, that is, phenolic content decreased more rapidly when strawberries were stored at 10°C than at 3°C. After 12 days of storage, phenolic content of strawberries stored at 10°C was reduced to 1,470 mg kg^{-1} from initial concentration of 2,630 mg kg^{-1} (Shin et al., 2008).

Conclusions

The sensory components important to overall strawberry quality and marketability such as color, firmness, and flavor deteriorated over the period of the handling simulation, with fruit from the fluctuating treatment showing a significantly higher decrease in the sensory quality than fruit from the control maintained constantly at 1°C. Such results were quantitatively confirmed by a decrease in the compositional attributes of strawberry fruit. Overall, strawberries from the fluctuating treatment had lower acidity and SSC, lower total sugar, total ascorbic acid, total anthocyanins and total phenolic contents compared to fruit from the control treatment. Furthermore, results obtained in this study validate the results obtained from field trials (Chapter 3) in which shipped fruit showed a lower overall quality upon arrival at the store compared to fruit maintained under steady conditions.

In order to improve the quality of strawberries, a constant low storage temperature (0-1°C) should be used throughout the entire handling process from the field to the store with minimal exposure of the fruit to higher temperatures. Small differences in the sensory and compositional quality of strawberries between control and fluctuating treatments towards the end of the handling simulation can be attributed to the advanced ripeness stage of the fruit from the late harvests used in this study, and most likely due to the adverse weather conditions experienced by the strawberry growers during this 2009 spring season. Rain delayed the harvesting of the strawberries until past the intended maturity stage. The results of this study reinforce the importance of reducing transit times, particularly during late season of harvest and/or during adverse weather conditions, while maintaining an optimum constant temperature during handling of strawberries from the field to the store.

Table 4-1. Simulated steps for strawberry handling and shipping from the field to the store.

Handling Step	Duration (hours)	Time elapsed (hours)	Temperature (°C)
Harvest	0	0	-
Harvest to pre-cool	5	5	30
Pre-cooling	2	7	3
Cold room	41	48	1
Shipping to DC [a]	115	163	3
Storage at DC	41	204	1
Transport from DC to store	4	208	4
Store	4	212	5

[a] DC = Distribution Center.

Table 4-2. Quality ratings and description for strawberry.

Quality attributes	Method used	Rating and description 1	2	3[a]	4	5	Reference
Color	Visual	Three-quarter colored to full red	Fully light red	Fully dark red	Very dark red (overripe)	Brownish-/purplish (extremely overripe)	Miszczak et al., 1995
Firmness	Tactile by gentle pressure	Extremely soft, deteriorated	Soft and leaky	Minor signs of softness	Firm	Very firm and turgid	Nunes et.al., 2003
Shriveling	Visual	Fresh/turgid fruit and calyx (field fresh)	Minor signs of shriveling, slightly wilted calyx	Shriveling evident, evident signs of moisture loss on fruit/calyx	Severe shriveling, fruit are shriveled and calyx is wilted/dry	Extremely wilted and dry, not acceptable under normal conditions	Nunes et al., 2003
Decay	Visual	0% decay	1-25% decay (brown/gray sunken minor spots)	26-50% decay; slight (spots with decay, some mycelium growth)	51-75% decay; moderate to severe	76-100% decay; severe to extreme (partial or completely rotten)	Nunes et al., 2002
Taste	Gustative	Very poor (unpleasant taste, off-taste, fermented, musty, earthy, very sour, bitter)	Poor (fermented, unpleasant taste)	Acceptable (slightly less intense strawberry taste, may taste slightly earthy)	Good (fresh and sweet taste, less crisp than harvest)	Excellent (pleasant strawberry taste, very sweet, juicy, and crisp)	Nunes et al., 2002
Aroma	Olfactory	Very poor (unpleasant aroma, off-flavor, fermented, musty aroma)	Poor	Acceptable	Good	Excellent (characteristic strawberry odor)	Nunes et al., 2002

[a] Rating of 3 is considered the limit of acceptability before strawberries become unmarketable.

Table 4-3. Taste panel results for strawberry fruit samples comparing fresh, fluctuating, and control samples (first simulation/harvest).

Fruit sample	Rank total [a b]	Overall appearance [b c]	Overall acceptability [b c]	Firmness [b c]	Strawberry flavor [b c]	Sweetness [b c]
Fresh	170a	6.75a	6.60a	6.99a	6.11b	6.03b
Fluctuating	148ab	6.79a	6.79a	6.93a	6.61ab	6.43ab
Control	132b	7.09a	7.00a	6.91a	6.79a	6.65a

[a] Lowest rank total = most preferred; highest rank total = least preferred
[b] Treatments with same letters are not significant different.
[c] Scale: 1-9 (1-dislike extremely 9-like extremely)

Table 4-4. Taste panel results for strawberry fruit from control versus fluctuating temperatures (second simulation/harvest).

Fruit sample	Preferred sample (number of panelists) [a]	Overall appearance [b c]	Appearance of the calyx [b c]	Overall acceptability [b c]	Firmness [b c]	Strawberry flavor [b c]	Sweetness [b c]
Control	43	6.92a	6.54a	6.93a	7.12a	6.82a	6.50a
Fluctuating	31	6.55a	5.76b	6.65a	6.84a	6.38a	6.09a
No Preference	0						
Total	74						

[a] Minimum agreeing judgments necessary to establish significant differentiation was 46 panelists (5% significance level).
[b] Treatments with same letters are not significant different.
[c] Scale: 1-9 (1-Dislike extremely 9-Like extremely)

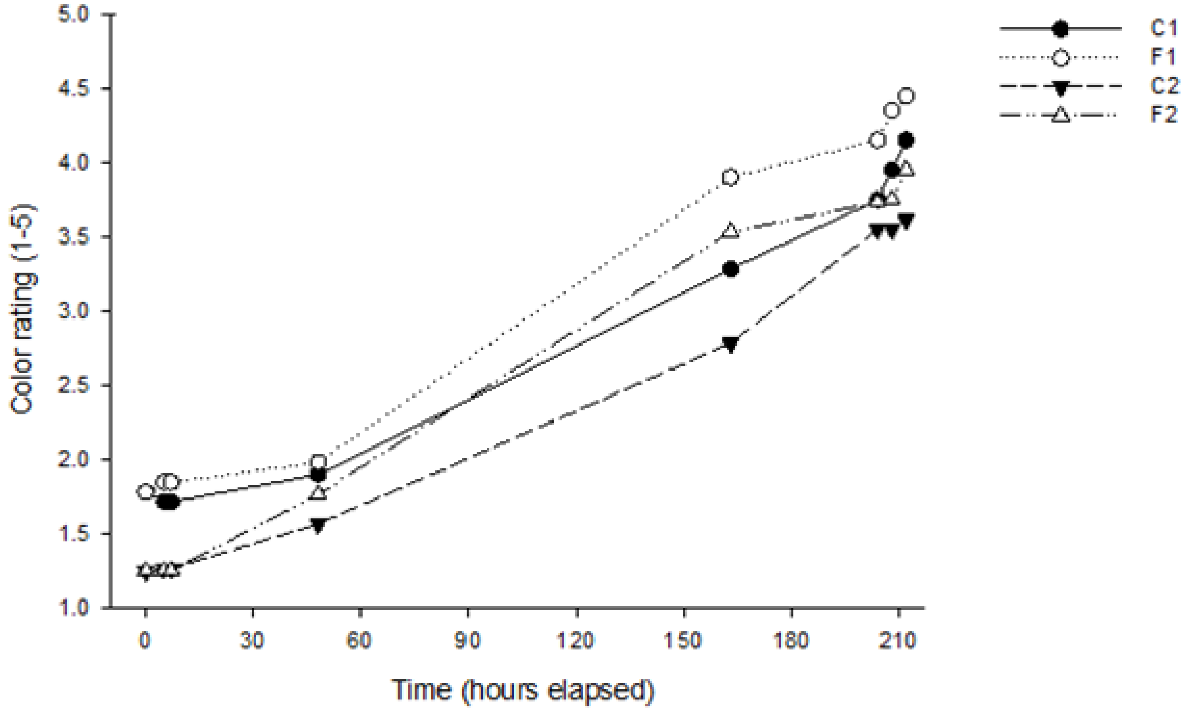

Figure 4-1. Color rating of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. $LSD_{0.05}$ = 0.093 (first simulation), $LSD_{0.05}$ = 0.098 (second simulation).

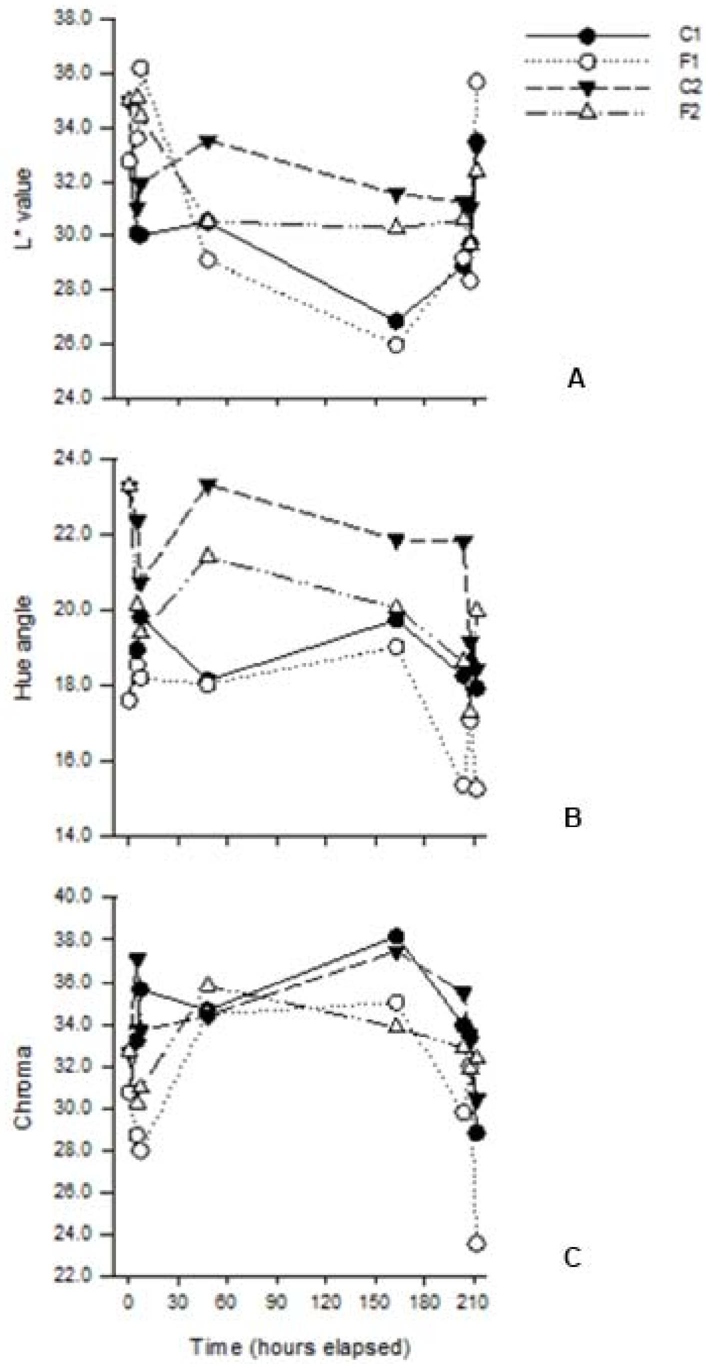

Figure 4-2. L*, hue, and chroma values of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. A) L* value: $LSD_{0.05}$ = 1.160 (first simulation), $LSD_{0.05}$ = 0.813 (second simulation). B) Hue angle: $LSD_{0.05}$ = 1.008 (first simulation), $LSD_{0.05}$ = 1.024 (second simulation). C) Chroma: $LSD_{0.05}$ = 1.405 (first simulation), $LSD_{0.05}$ = 1.011 (second simulation).

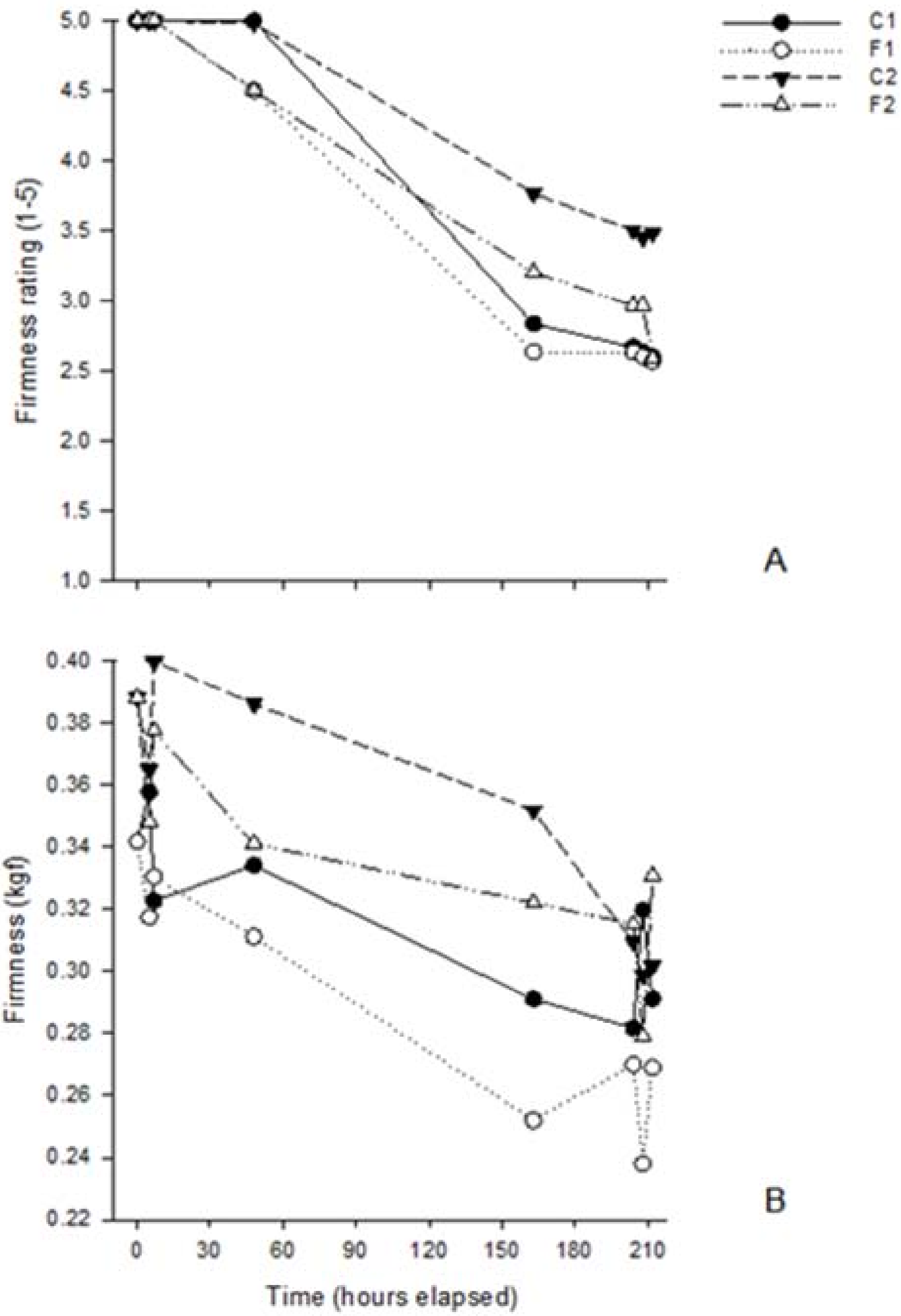

Figure 4-3. Firmness of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. A) Firmness rating: $LSD_{0.05} = 0.049$ (first simulation), $LSD_{0.05} = 0.092$ (second simulation). B) Firmness quantitative: $LSD_{0.05} = 0.023$ (first simulation), $LSD_{0.05} = 0.017$ (second simulation).

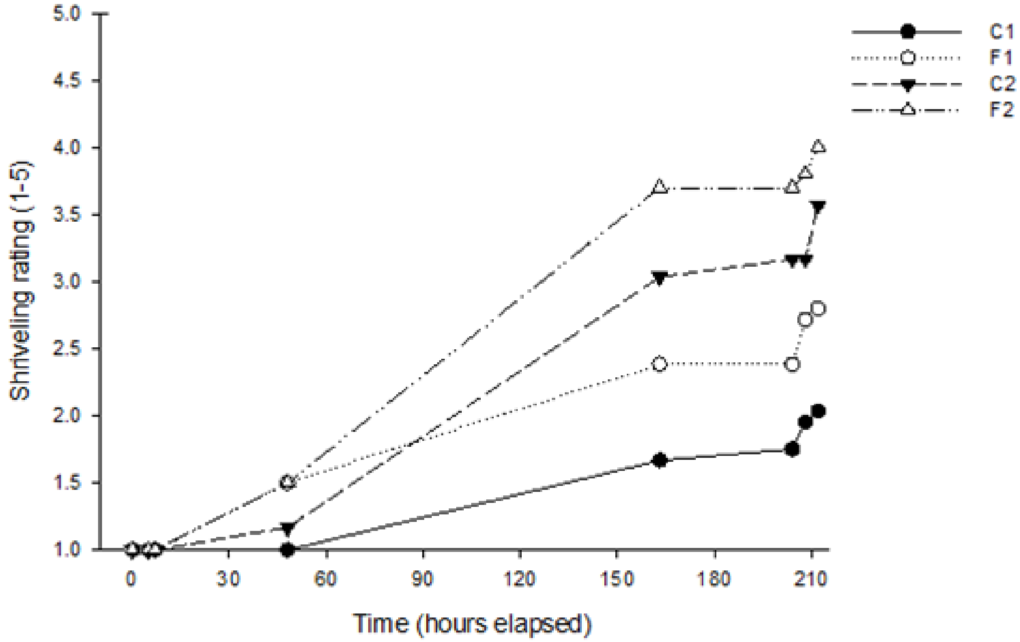

Figure 4-4. Shriveling ratings of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. $LSD_{0.05}$ = 0.072 (first simulation), $LSD_{0.05}$ = 0.080 (second simulation).

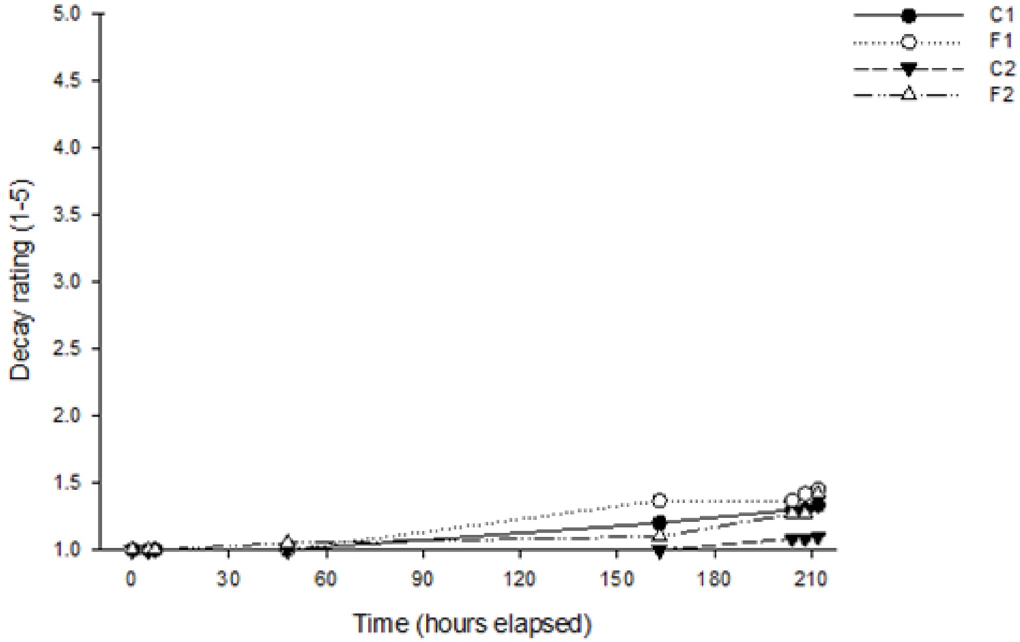

Figure 4-5. Decay rating of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. $LSD_{0.05}$ = 0.040 (first simulation), $LSD_{0.05}$ = 0.046 (second simulation).

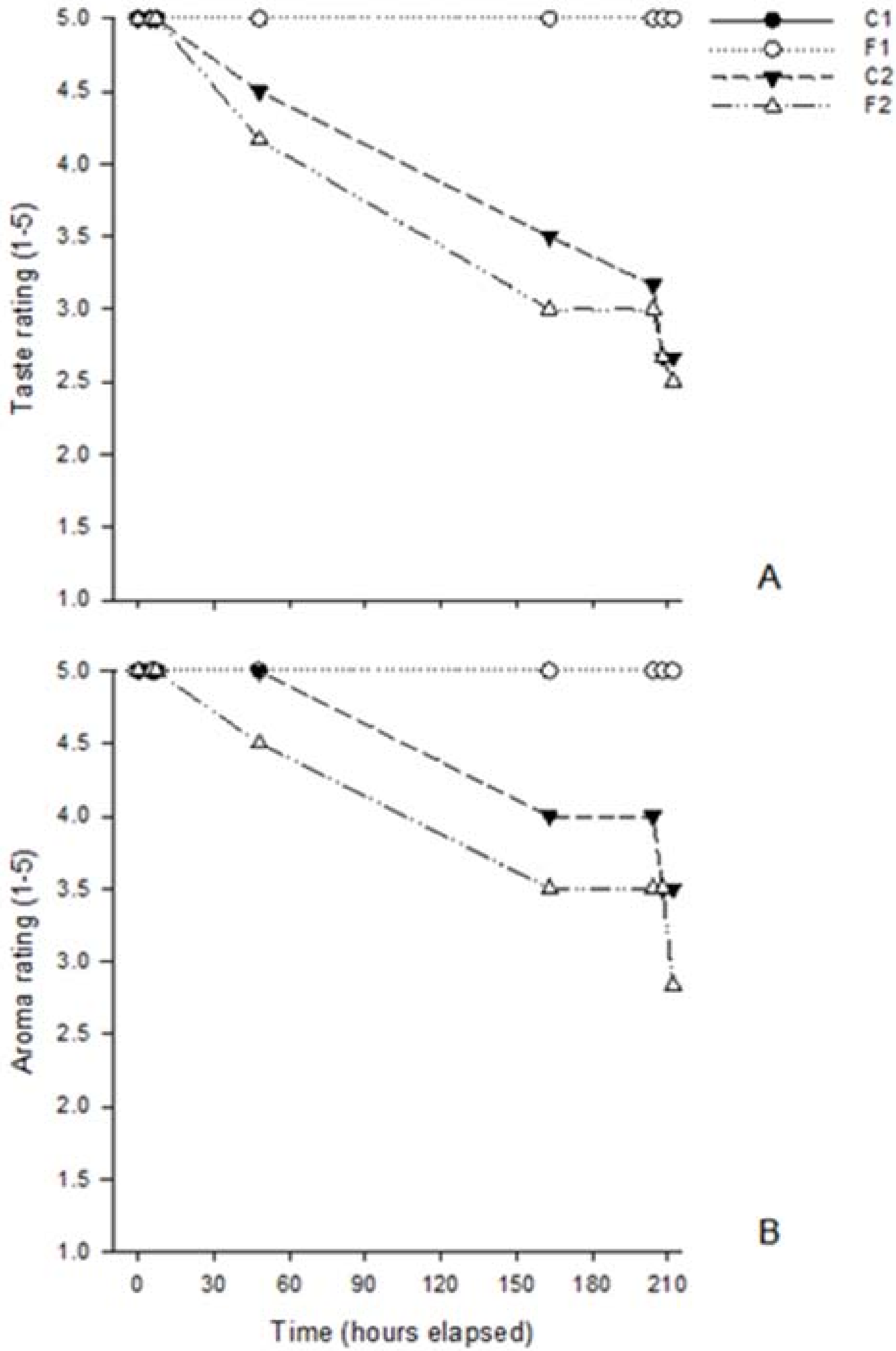

Figure 4-6. Taste and aroma ratings of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. A) Taste: $LSD_{0.05}$ = 0.000 (first simulation), $LSD_{0.05}$ = 0.251 (second simulation). B) Aroma: $LSD_{0.05}$ = 0.000 (first simulation), $LSD_{0.05}$ = 0.042 (second simulation).

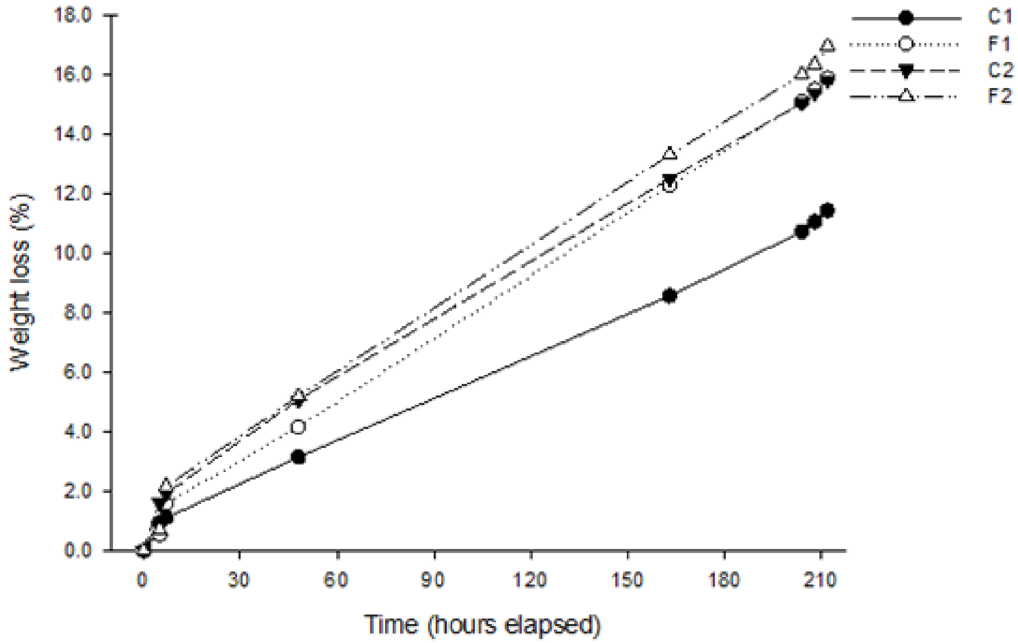

Figure 4-7. Weight loss of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. $LSD_{0.05}$ = 0.255 (first simulation), $LSD_{0.05}$ = 1.170 (second simulation).

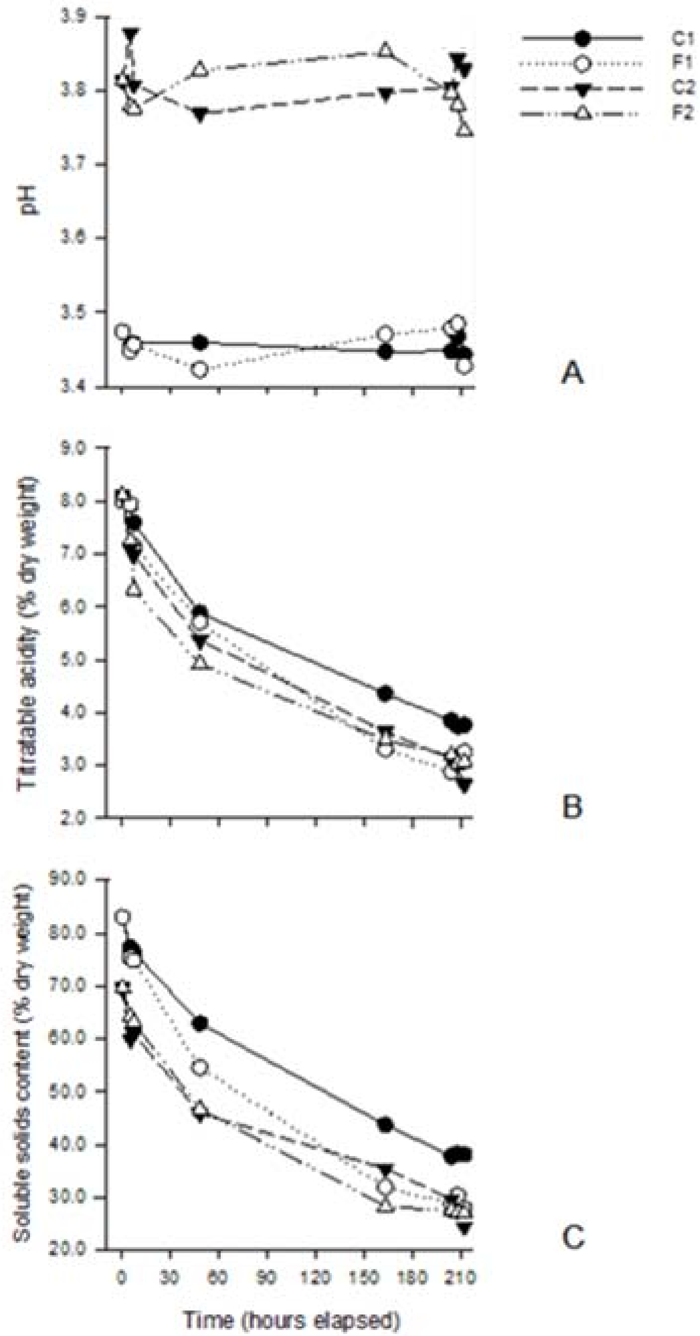

Figure 4-8. pH, titratable acidity (TA), and soluble solids content (SSC) of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. A) pH: $LSD_{0.05} = 0.011$ (first simulation), $LSD_{0.05} = 0.009$ (second simulation). B) Titratable acidity (TA): $LSD_{0.05} = 0.094$ (first simulation), $LSD_{0.05} = 0.207$ (second simulation). C) SSC: $LSD_{0.05} = 0.766$ (first simulation), $LSD_{0.05} = 1.484$ (second simulation).

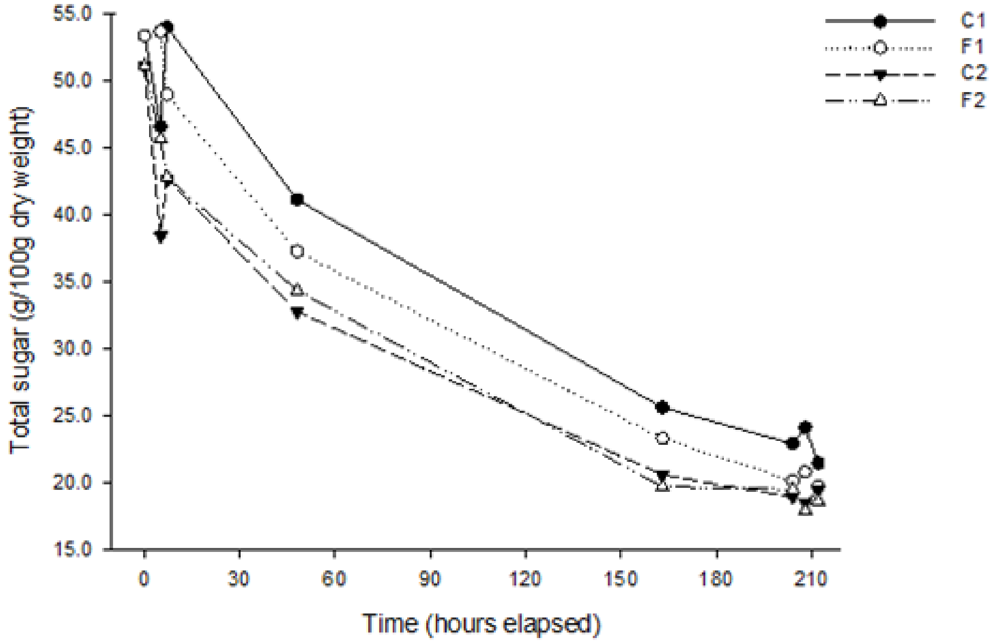

Figure 4-9. Total sugar content of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. $LSD_{0.05}$ = 0.212 (first simulation), $LSD_{0.05}$ = 0.108 (second simulation).

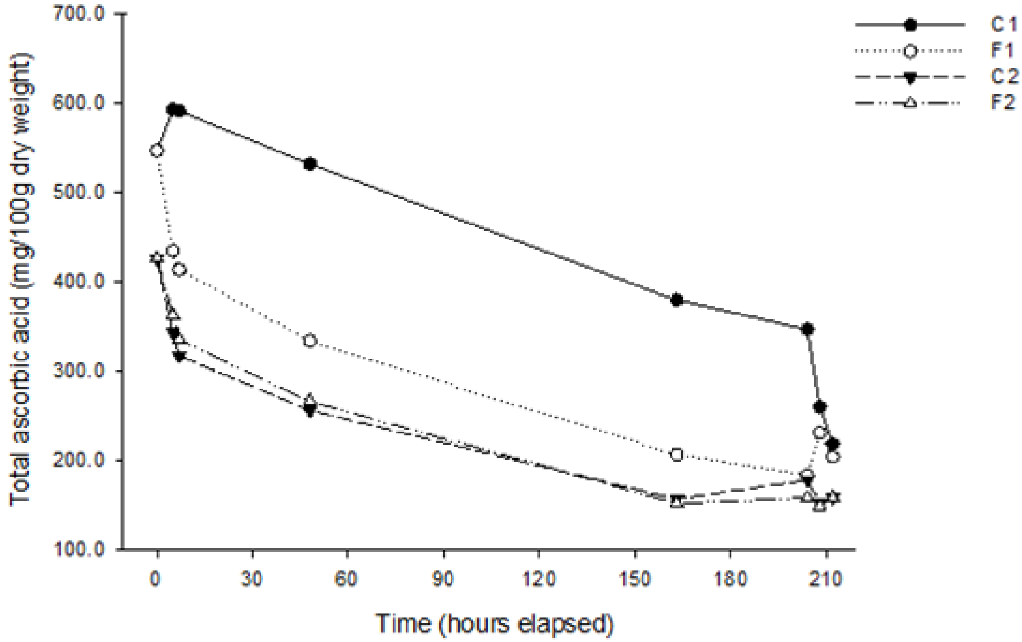

Figure 4-10. Total ascorbic acid content of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. $LSD_{0.05}$ = 0.419 (first simulation), $LSD_{0.05}$ = 0.339 (second simulation).

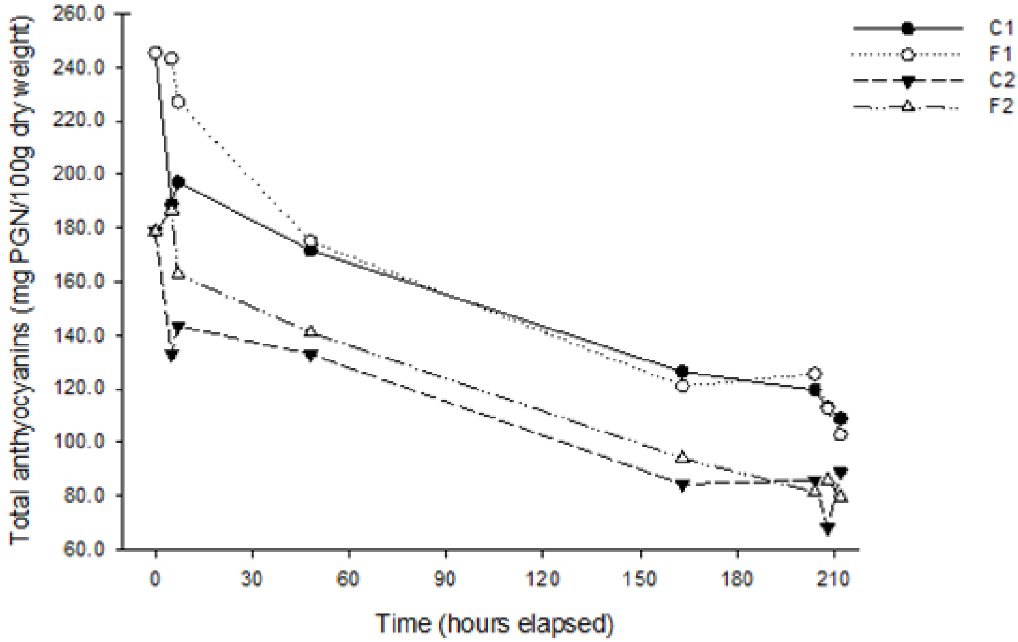

Figure 4-11. Total anthocyanin content of strawberries during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. $LSD_{0.05}$ = 7.445 (first simulation), $LSD_{0.05}$ = 6.263 (second simulation).

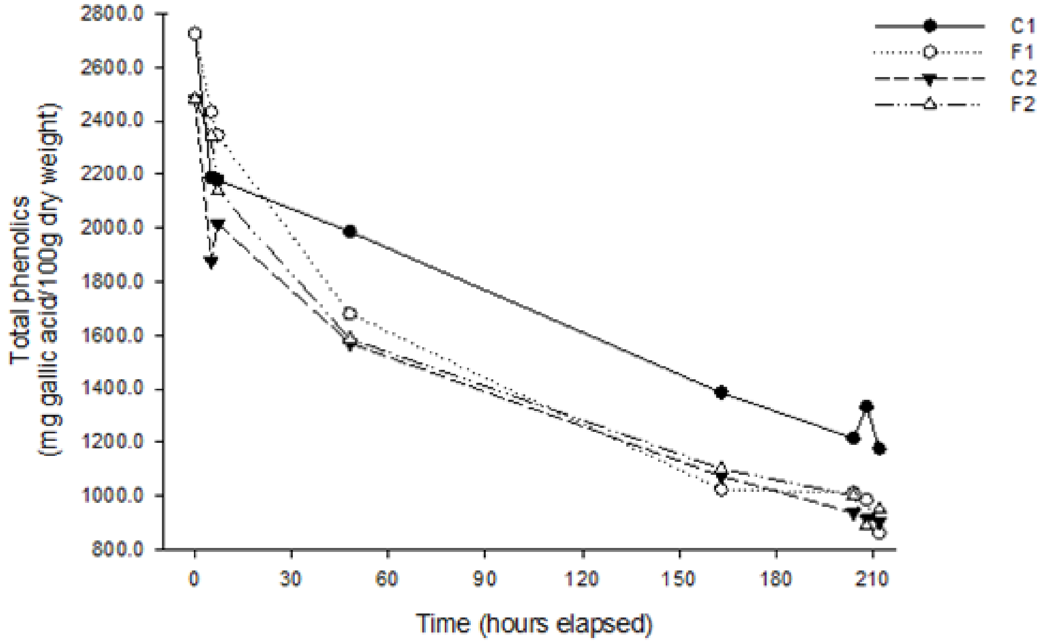

Figure 4-12. Total phenolics content of strawberry during simulated handling and distribution from the field to the store. C1 = control first simulation; F1 = fluctuating first simulation; C2 = control second simulation; F2 = fluctuating second simulation. $LSD_{0.05}$ = 23.056 (first simulation), $LSD_{0.05}$ = 49.154 (second simulation).

CHAPTER 5
QUALITY ATTRIBUTES AND SHELF LIFE OF 'ALBION' STRAWBERRY FRUIT STORED AT DIFFERENT TEMPERATURES

Introduction

Strawberries are fragile fruit and their quality and shelf life is greatly dependent on the environmental conditions to which the fruit were exposed during distribution from the field to the store. In fact, as shown in Chapter 3, non-optimum environmental conditions combined with long shipping times resulted in poor fruit quality at the distribution and retail level.

Among the environmental factors that significantly affect strawberry quality, temperatures have been shown to have the greatest impact on fruit quality (Collins and Perkins-Veazie, 1993; Kalt et al., 1993; Nunes et al., 2006). For maximum shelf life (approximately 7 to 10 days) and best overall quality, strawberries should be stored at 0°C and 90-95% RH (Kader, 2002; Zhao, 2007). If stored at temperature above the optimum, strawberry shelf life is significantly reduced due to accelerated visual and compositional quality deterioration. For example, Collins and Perkins-Veazie (1993) reported that for each 5°C rise in the storage temperature above 0°C, strawberry color deterioration doubled or tripled and the fruit becomes brownish-red. Firmness of strawberry is also greatly affected by storage temperature, with fruit stored at higher temperatures (10°C) showing increased softening compared to fruit stored at low temperatures (3°C) (Shin et al., 2008). Parallel to visual changes in the color of the fruit, anthocyanin content increases as temperature increases from 5 to 20°C (Kalt et al., 1993). On the other hand, decreased in ascorbic acid (AA) was more accentuated when strawberries were stored at 20°C compared to storage at 1°C (Nunes et al., 1998). Souble solids content (SSC) followed the same trend, with strawberry stored at 10°C showing the most reduction in SSC than fruit stored at 5 or 0°C (Ayala-Zavala et al., 2004).

Although the effect of temperature on strawberry quality is well documented, no data was found in the literature regarding quality curves for ‘Albion’ strawberry stored at various temperatures. Furthermore, no information was found regarding sensory quality attributes that are the most important to determine the limits of marketability for ‘Albion’ strawberry stored at various temperatures. The objective of this work was to determine the maximum shelf life of ‘Albion’ strawberries at each temperature, and to identify which sensory quality attributes limit the marketability of the fruit stored at different temperatures. More specifically, the effects of five different constant storage temperatures (i.e., 1, 6, 10, 15 and 21°C) were evaluated on the sensory and compositional attributes of ‘Albion’ strawberries.

Materials and Methods

Plant Material and Storage Conditions

‘Albion’ strawberry fruit were obtained from a commercial field in Floral City, Florida. Fruit were removed from the field with minimal delay after harvest and transported to the laboratory in Gainesville, Florida within approximately 2 to 3 hours. Strawberries were harvested twice during the 2009 spring season on February 10 and March 9. For each harvest, and upon arrival at the laboratory, a total of 1,080 strawberry fruit were selected (from 8 flats containing 8-454 g clamshells each) for uniformity of color, size and freedom of defects: 30 fruit were used for initial quality evaluations; 150 fruit were used for non-destructive quality evaluation and 900 fruit for destructive daily evaluation were redistributed through 5 temperature and humidity controlled chambers (Forma Environmental Chambers Model 3940 Series, Thermo

Electron Corporation, OH, USA) set at 1, 6, 10, 15 and 21°C and 80-87% RH. Strawberry fruit were stored during an 8 to 10-day period, depending on the harvest.

Sensory Evaluation

The subjective quality attributes, color, firmness, shriveling, decay, taste, and aroma were evaluated either by visual, tactile, gustatory, or olfactory methods using 1-5 rating scales always by the same trained person (Table 5-1). A rating of 3 was considered to be the limit of acceptability for sale. For each temperature treatment, the same 30 strawberries were used for non-destructive quality evaluations (weight loss, color, firmness, shriveling and decay) at each handling step. For taste and aroma evaluations, 30 different strawberries per treatment were used at each handling step, due to the destructive nature of the evaluations. These 30 strawberry fruit were then used for the remaining destructive analysis.

Objective Color Measurements

Surface color measurements (L*a*b*) of 30 individual strawberries per treatment were taken with a reflectance colorimeter (Model CR-300, Minolta Co., Ltd., Osaka, Japan) on opposite sides of each fruit at the equatorial region for a total of two measurements per fruit. Color was recorded using the CIE-L*a*b* uniform color space (CIE-Lab), L* (lightness), a* (redness), and b* (yellowness) values. Numerical values of a* and b* were converted into hue angle ($\tan^{-1} b^*/a^*$) and chroma [$(a^{*2} + b^{*2})^{1/2}$] (Francis 1980).

Firmness Evaluation

Firmness of 30 individual strawberries per treatment was measured using a TA.XT plus Texture Analyzer (Texture Technologies Corp., NY, USA) fitted with a 7.9 mm diameter convex probe, and equipped with a 50-kg load cell. The probe was driven with a crosshead speed of 1 mm·sec^{-1}. The force was recorded at 3.0 mm deformation. The measurements were made on the equatorial region of each fruit.

Compositional Analysis

Weight loss

Weight of strawberries was measured using a precision balance with an accuracy of ±0.015 g (Setra Model 5000L, Setra Systems, MA, USA). Weight loss was calculated from the weight of each subsample of 10 strawberries (3 subsamples per treatment) measured initially and every day during an 8 or 10-day storage period depending on the harvest. These 30 strawberries were the same used for the non-destructive sensory evaluations. Concentrations of chemical constituents were expressed in terms of dry weight in order to show the differences between treatments that might be obscured by differences in water content. The following formula was used for water loss corrections: [chemical component (fresh weight) × 100 g / 4.8 g (strawberry average dry weight) + weight loss during storage (g)].

pH, titratable acidity (TA), and soluble solids content (SSC)

Each individual replicated sample was thawed, and a 50-g aliquot of the tissue slurry was centrifuged at 6,000 × g for 20 min. The clear juice was decanted from the centrifuge tubes and the pH was determined using a pH meter (Accumet model 15, Fisher Scientific, Arvada, Colo., USA) that had been previously standardized to pH 4 and pH 7. Aliquots (6.00 g) of the juice were diluted with 50 mL distilled water and the titratable acidity (TA) determined by titration with 0.1 *N* NaOH to an end point of pH 8.1 with an automatic titrimeter (Titration Unit TitroLine easy, SCHOTT-GERÄTE Instruments GmbH, Germany). The results were converted to percent of citric acid [(mL NaOH × 0.1 *N* × 0.064 meq·6.00 g of juice^{-1}) × 100] and expressed in terms of dry weight. The SSC of the resulting clear juice samples was as measured with a digital refractometer (Palette PR-101, 0-45 °Brix, Atago Co. LTD, Tokyo, Japan). The SSC of strawberry was expressed in terms of dry weight.

Total sugar content

Total sugar analysis was conducted using a Hitachi HPLC system with a RI-refractive index detector and a 300 mm × 8 mm Shodex SP0810 column (Shodex, Colorado Springs, CO) with a SP-G guard column (2 mm x 4 mm). Isocratic solvent delivery of water was set at 1.0 mL/min. Sample injection volume was 5 µL. Several standards including sucrose, glucose, and fructose were used to identify sample peaks. After comparison of retention time with the standards, the peaks were identified. The amount of total sugar in strawberry was quantified using calibration curves obtained from different concentrations of sucrose and glucose standards. Three samples were used for each time with duplicate HPLC injections to be used as three replications. Total sugar content was expressed in g/100g dry weight.

Total ascorbic acid content

After weighing 2 g of homogenized strawberry tissue in a 50 mL tube, 20 mL metaphosphoric acid mixture (6% HPO_3 containing 2 *N* acetic acid) was added and mixed thoroughly. Samples were then filtered through a 0.22 μm filter prior to HPLC analysis. AA analysis was conducted using a Hitachi LaChromUltra UHPLC system with a diode array detector and a LaChromUltra C18 2μm column (2 × 50 mm) (Hitachi, Ltd., Tokyo, Japan). The analysis was performed under isocratic mode at a flow rate of 0.5 mL/min with a detection of 254 nm. Sample injection volume was 5 µL. Mobile phase was buffered potassium phosphate monobasic (KH_2PO_4, 0.5%, w/v) at pH 2.5 with metaphosphoric acid (HPO_3, 0.1%, w/v). Retention time of AA peak was 0.35 min. After comparison of retention time with the AA standard, the peak was identified. Amount of total ascorbic acid content in strawberry was quantified using calibration curves obtained from different concentrations of AA standards. Three samples were used for each time with duplicate HPLC injections to be used as three replications. Total ascorbic acid content was expressed in mg/100g dry weight.

Total phenolic content

Total soluble phenolic compounds were measured using the Folin-Ciocalteu reagent (Folin and Ciocalteu 1927; Singleton and Rossi 1965). Aliquots (0.50 mL) of clear strawberry juice were diluted in 9.5mL deionized water, and to 1 mL of the resulting solution was added 5 mL of diluted (1:9) Folin-Ciocalteu reagent. Between 0.5 and 8 min after addition of the Folin-Ciocalteu reagent, 4 mL of sodium carbonate solution (0.075 g/mL) was added. After 1 h at 30°C plus 1 h in ice (0°C), the absorbance of the solution was measured at 760 nm. Gallic acid was used as the standard, and the concentration of total soluble phenolics was expressed as mg/100 g fruit dry weight.

Total anthocyanin content

Three replicate samples of 10 fruit per treatment were homogenized in a laboratory blender at high speed for 2 min. Aliquots (2.00 g) of homogenized strawberry fruit tissue were mixed in 18 mL of 0.5% (v/v) HCl in methanol and held for 1 h at 4°C to extract the pigment. The flocculate was removed by filtering the extract through a single layer of facial tissue and absorbance of the resulting clear liquid containing the pigments was measured at 520 nm (maximum absorbance for anthocyanins). Pigment content was calculated using the following formula: A520 × dilution factor × [molecular weight (MW) of PGN/molar extinction coefficient] where MW of PGN = 433.2 and the molar extinction coefficient = 2.908 × 104. Results were expressed as mg PGN /100g dry weigh (PGN = pelargonidin-3-glucoside which is the major pigment in strawberry).

Statistical analysis

The analysis of variance was performed using the Statistical Analysis System 9.1 Computer Package (SAS Institute, Inc., Cary, N.C.). Data from the two harvests were analyzed separately as initial statistical analysis showed significant differences between harvests for most of the factors evaluated. Significant differences among the storage temperatures were detected using the least significant difference (LSD) test at the 5% level of significance. For each of the storages temperature Pearson's correlation coefficients (r) were calculated between subjective firmness and analytical firmness measurements and between SSC and total sugar content during storage at different temperatures.

Results and Discussion

Sensory Evaluation

Color

Color of strawberries changed during storage from three-quarter colored (second harvest) or full red (first harvest) to very dark red (second harvest) or brownish-red (first harvest), regardless of the storage temperature (Figure 5-1). However, color of strawberries stored at 20°C deteriorated faster than that of fruit stored at lower temperatures. In the first harvest, there was no significant difference between the color of strawberries stored at temperatures lower than 20°C, whereas in the second harvest there was a noticeable difference between the color of the fruit stored at 1 or 6°C and that of fruit stored at 10 or 15°C. Color ratings for strawberries stored at 21°C increased faster and were higher than the other temperatures. Therefore, while color of strawberries stored at 21°C attained a rating of 3 (fully dark red) after approximately 2 days, color of the fruit stored at lower temperatures was still not entirely dark red. Color of fruit stored at 10 and 15°C attained a rating of 3 after approximately 3.5 and 3 days, respectively, whereas strawberry stored at 1 or 6°C was fully dark red after 5 days (Figure 5-1B).

L*, chroma and hue values of strawberries decreased during storage, regardless of the temperature. That is, the fruit became darker, less vivid and redder or brownish-red as storage progressed (Figure 5-2). Hernandez-Munoz et al. (2008) also reported a decrease in the L*, chroma and hue values of strawberries during storage for 6 days at 10°C. In the current study, strawberries stored at 21°C had lower L* values (darker), lower chroma (less vivid), and lower hue (less red) values than fruit stored at lower temperatures. Fruit stored at 1 or 6°C tended to have higher chroma (more vivid) and higher hue (more red) than those stored at higher temperatures. There were no significant differences in the L* values of strawberries stored at 10, 15 or 21°C and the rest of the temperatures. Strawberries stored at 21°C had a significantly lower chroma value than fruit from the other temperatures. This was also mostly true for hue values. There were no significant differences between temperatures for hue and L* values of strawberries from the second harvest. For chroma, 1 and 6°C were significantly different from the other temperatures. Previous studies have also reported no significant differences in the color of strawberries stored for 13 days at temperatures between 0 and 10°C (Perez et al., 2001; Ayala-Zavala et al., 2004; Gil et al., 2006; Zheng et al., 2007; Nielsen et al., 2008).

Firmness

Firmness of strawberries from both harvests significantly decreased regardless of the temperature (Figure 5-3). However, fruit stored at 10, 15 or 21°C softened faster than fruit stored at 1 or 6°C. Subjective evaluations showed that firmness of strawberries from the first harvest stored at 21°C attained a rating of 3 (minor signs of softness) after 2 days whereas fruit from lower temperatures maintained an acceptable texture after approximately 7 days of storage (Figure 5-3A, Figure 5-3C). For the second harvest, there was a markedly difference between temperatures with firmness of strawberries stored at 10, 15 or 21°C reaching a rating of 3 after approximately 2.5, 3 and 4 days, respectively (Figure 5-3B, Figure 5-3D). Firmness of fruit stored at 1 or 6°C attained a rating of 3 after 7 and 8 days, respectively. Overall, there was a significant difference in the firmness of strawberry between each temperature treatment.

Results obtained from quantitative firmness measurements supported those obtained from subjective evaluations. That is, firmness of fruit measured with a texture analyzer showed similar decreasing trend during storage compared to sensory evaluations (Figure 5-3C, Figure 5-3D). Again, fruit stored at 21°C softened significantly faster than those stored at lower temperatures with fruit stored at 1 or 6°C being firmer than those stored at higher temperatures.

Similar results were previous reported by others (Perez et al., 2001; Gil et al., 2006; Shin et al., 2007; Hernandez-Munoz et al., 2008; Shin et al., 2008). For example, Shin et al. (2007) showed that firmness of strawberries stored at 20°C decreased as days elapsed and, as seen in the current study, softening occurred faster in fruit stored at 21°C than in those stored at 10 or 0.5°C. Softening of the fruit is the result of the loss of cell wall material mainly in the cortical tissue (Koh and Melton, 2002). According to

Brummell et al. (1999), loosening of fruit cell wall that occurs initially is mediated by expansins, followed by depolymerization of hemicelluloses, and finally polyuronide depolymerization by polygalacturonase or other hydrolytic enzymes.

Decrease in firmness of strawberry fruit during storage parallels the decrease in subjective firmness ratings and a significant positive correlation was found between firmness measured analytically and firmness measured using a rating scale (Table 5-2). Therefore, the use of subjective rating scales to evaluate firmness changes in strawberries can be used as a simple method to estimate textural changes in strawberries when more sophisticated methods of analysis are not available.

Shriveling

For both harvests, shriveling increased during storage regardless of the temperature (Figure 5-4). Differences in shriveling of fruit exposed to different temperatures were more pronounced in strawberries from the second harvest compared to the first harvest. There were no significant differences between shriveling rating of strawberries stored at 1 or 6°C, or 10 or 15°C, but the two temperature groups were significantly different from each other. Shriveling of strawberries stored at 21°C was significantly different from all the temperature treatments. After day 2, strawberries stored at 21°C showed more shriveling than fruit stored at lower temperatures, which rendered the appearance of the 21°C fruit unacceptable (Figure 5-4B). Shriveling of strawberries stored at 10°C or 15°C was similar and attained the acceptability limit (rating of 3) after approximately 3.5 days, whereas shriveling of fruit stored at 6°C was higher than for fruit stored at 1°C – attaining the limit of acceptability after 4 and 5.5 days, respectively. By the end of the storage period, strawberry fruit from all temperatures appeared severely shriveled with wilted or dry calyxes. Development of shriveling in fruit and vegetables is primarily related to loss of water during storage. For example, Hernandez-Munoz et al. (2008) reported less weight loss, least reduction in firmness, and better overall appearance in coated strawberries compared to non-coated fruit. Furthermore, Ayala-Zavala et al. (2004) suggested that the major cause of strawberry deterioration during storage for 13 days at 0, 5, or 10°C was due to water loss causing reduction in fruit turgidity.

Decay

Decay increased during storage regardless of the temperature (Figure 5-5). However, decay attained maximum acceptable levels (rating of 3; spots with decay) earlier (after approximately 3.5 days) in fruit from the second harvest stored at 21°C compared to other temperatures. Overall, development of decay was faster and more severe in fruit stored at temperatures higher that 1°C. Other studies have shown similar results with decay increasing faster as temperature increased (Ayala-Zavala et al., 2004; Shin et al., 2007). For example, Ayala-Zavala et al. (2004) showed that storing strawberries at 0°C was more effective in suppressing decay for 7 days compared to storage at 10°C, which resulted in rapid increase in decay. Another study, by Shin et al. (2007), reported that strawberries stored at 0.5°C had no fungal growth after 4 days while 90% of the fruit stored at 20°C showed signs of decay.

Taste and aroma

Volatiles are crucial compounds as they contribute to the characteristic strawberry aroma and flavor (Zhao, 2007). However, temperature has a significant effect on the production of aroma volatiles. For example, Ayala-Zavala et al., (2007) reported that the production of aroma volatiles in ‘Chandler’ strawberry such as methyl acetate, methyl metanoate, ethyl butanoate, butyl acetate, and hexyl acetate was faster and higher in strawberries stored at 10°C than in fruit stored at 5 or 0°C.

In this study, taste and aroma measured by sensory evaluation showed similar decreasing trends in terms of quality ratings (Figure 5-6). However, taste and aroma of strawberries at 21°C deteriorated faster than that of fruit stored at lower temperatures. After approximately 4 days, taste and aroma of strawberries stored at 21°C for both harvests were considered unacceptable while the taste and aroma of fruit stored at 1°C for second harvest never reached unacceptable levels.

Compositional Analysis

The high levels of water loss observed in strawberries during storage at different temperatures tended to mask real losses on a fresh weight basis of some constituents - in some cases seeming to show no difference, or even greater retention of some constituents compared to the strawberries from the control treatments. Although it might be argued that the compositional values expressed on a fresh weight basis represent the actual concentrations that would be experienced by consumers, the compositional data is expressed on a dry weight basis in order to illustrate the actual losses that occurred in certain constituents irrespective of the concentrating effect imposed by water loss.

Weight loss

Weight loss in strawberries from both harvests increased linearly throughout storage; however weight loss was higher in fruit from the first harvest compared to the second harvest (Figure 5-7). For both harvests, the percentage of weight loss seemed to separate the temperature treatments into three main groups (1 and 6°C; 10 and 15°C; and 21°C). Strawberries from both harvests stored at 21°C showed the highest amount of weight loss compared to fruit stored at lower temperatures. For example, after 5 and 4 days, which corresponded to the maximum storage time at 21°C for the first and second harvest, respectively, fruit stored at 1°C had lost 7.2 and 4.4%, whereas fruit stored at 21°C had lost 13.7 and 10.4% of their initial weight. These findings are in agreement with results by Shin et al. (2007) in which, after 3 days, strawberry weight loss was the highest and increased fastest in fruit stored at 20°C (0.5% at 95% RH), second highest at 10°C (0.4% at 95% RH), and the lowest at 0.5°C (0.38% at 95% RH).

According to Robinson et al. (1975), the maximum acceptable weight loss before strawberries become non-salable is 6.0%. In this study, weight loss attained the non salable limit after approximately 2 and 3 days for strawberries from the first and second harvest stored at 21°C, respectively. Weight loss of fruit from the first harvest stored at 1 or 6°C attained the non-salable value after 4 days of storage (Figure 5-7A), whereas in fruit from the second harvest non-saleable weight loss values were attained after approximately 7 days of storage (Figure 5-7B). However, shriveling attained objectionable levels after weight loss was considered unacceptable. Unacceptable shriveling rates corresponded to weight loss that ranged from approximately 7 to 14% for fruit from the first harvest and from approximately 5 to 6% for fruit from the second harvest. Another study showed however that after approximately 3 days at 20°C, ‘Seascape’ strawberries had lost less than 3% of their initial weight, a value that was well below the maximum previously considered acceptable for strawberry. Nevertheless, softening in strawberries stored at 20°C attained a moderate to severe rating after approximately 2.5 days, which corresponded to a weight loss of 2.5%, while shriveling of the fruit and dryness of the calyx became evident when weight loss attained 3.0% (Nunes and Emond, 2007). Therefore, maximum acceptable weight loss for strawberry should not be generalized nor should it be based only on the development of shriveling. In fact, deterioration of visual quality may not be exclusively attributed to water loss, but rather to a summation of many appearance defects, some of which may result from excessive loss of water (Nunes and Emond, 2007).

pH, titratable acidity (TA), and soluble solids content (SSC)

For the first harvest, pH of the fruit slightly increased initially, particularly in fruit stored at 10, 15 or 21°C, but then remained stable for the rest of the storage period, with fruit stored at 15 or 21°C having a slightly higher pH that those stored at 1 or 6°C (Figure 5-8A). In the second harvest, changes in pH were more subtle and by the end of the storage period there was no significant difference in the pH of the fruit stored at different temperatures (Figure 5-8B). Others studies have reported similar results for pH of strawberries stored at different temperatures (Ayala-Zavala et al., 2004; Shin et al., 2007). For example, strawberries stored at 0°C had the same pH after 13 days of storage while pH slightly increased by 0.04 in fruit stored at 5°C (Ayala-Zavala et al., 2004). Shin et al. (2007) also found that pH remained consistently around 3.09 during 4 days storage at 0.5, 10 or 20°C.

Initial TA of strawberry, on a fresh weight basis, was similar for the first (0.8%) and second harvests (0.9%). During storage, TA significantly decreased regardless of the storage temperature (Figure 5-8). However, reduction in TA of fruit stored at 10, 15 or 21°C was faster and higher than that of fruit stored at 1 or 6°C. In both harvests, by the end of the storage period TA of strawberry stored at 1 or 6°C was not significantly different from each other. Fruit stored at 21°C was significantly lower than the other temperatures throughout most of the storage period. Ayala-Zavala et al. (2004) found no significant effect of storage temperatures on TA of strawberry, but did not consider the weight loss of the fruit during storage.

Initial SSC of strawberry, on a fresh weight basis, was similar for the first (9.8%) and second harvests (9.6%). During storage, SSC significantly decreased regardless of the storage temperature; however, the decrease was more accentuated in fruit from the first harvest compared to the second harvest, particularly in fruit stored at 1 or 6°C (Figure 5-8). Decrease in SSC was significantly faster and greater in strawberries stored at 21°C while in fruit stored at 1 or 6°C the decrease in SSC was lower and slowest. For example, after 4 days, in strawberry from both harvests, the initial SSC of fruit stored at 21°C was reduced by approximately 48%, whereas after 4 days, fruit from the first and second harvest stored at 1°C had lost 32 and 26% of their initial SCC, respectively. This trend was seen also in a study by Emond et al. (2004) where, after 6 days of storage at 0°C, SSC decreased the least (by 34.97%) and the most at 20°C (by 61.47%).

Total sugar content

At the time of harvest, total sugar content of strawberries from the first harvest (7.2 g/100 g fruit fresh weight) was not significantly different than that of fruit from the second harvest (6.9 g/100 g fruit fresh weight). During storage, total sugar content of strawberries from both harvests decreased regardless of the storage temperature (Figure 5-9). This decreasing trend agreed with results from Cordenunsi et al. (2003) who found a similar decline in sugar content of strawberries stored for 3 days at 6°C. However, by the end of the storage period strawberries stored at 15 or 21°C had significantly lower sugar content than those stored at lower temperatures. For example, after 4 days, the average sugar content of fruit from the first harvest stored at 15 or

21°C was 27 g/100 g fruit dry weight, whereas the average sugar content of fruit stored at 1 or 6°C was 41 g/100 g fruit dry weight. Similarly, after 4 days, the average sugar content of fruit from the second harvest stored at 15 or 21°C was 31 g/100 g fruit dry weight, whereas average sugar content of fruit stored at 1 or 6°C was 41 g/100 g fruit dry weight.

Decrease in total sugar content during storage parallels the decrease in SCC and a significant positive correlation was found between SSC and total sugar content of strawberries (Table 5-3). Therefore, measurement of SSC in strawberries can be used as a simple method to estimated changes in their total sugar content when more sophisticated methods of analysis are not available.

Total ascorbic acid content

Initial AA content of strawberries from the first harvest (53 mg/ 100g fruit fresh weight) was slightly higher than that of fruit from the second harvest (51 mg/100 g fruit fresh weight). During storage, AA decreased in fruit from both harvests regardless of the storage temperature (Figure 5-10). However, strawberries stored at 1°C showed the slowest reduction of AA over time. Differences in AA content of fruit stored at different temperatures were more evident in the first harvest, with strawberries stored at 21°C showing the most reduction in AA, followed by fruit stored at 10°C or 15°C, and finally fruit stored at 1 or 6°C having the least reduction of AA over time (Figure 5-10A). In the second harvest, although differences between temperatures were less evident, AA content of strawberries was the highest in fruit stored for 8 days at 1°C (326 mg/ 100 g fruit dry weight) and the lowest in fruit stored for 5 days at 15°C (244 mg/100 g fruit dry weight) or for 4 days at 21°C (265 mg/100 g fruit dry weight) (Figure 5-11B). Nunes et al. (1998) also found that AA levels were higher in strawberries (‘Chandler’, ‘Oso

Grande,' and 'Sweet Charlie') stored for 8 days at 1°C compared to AA content of fruit stored at 20°C.

Total anthocyanin content

Anthocyanins, namely pelargodini-3-glucoside, are the major pigments in strawberry and are responsible for the red color of the fruit (Zhao, 2007). As strawberries ripen on the plant, anthocyanins tend to increase while chlorophyll decreases (Zhao, 2007). During storage, although synthesis of anthocyanins may occur during the first days of storage at temperatures above 5°C, if stored for longer periods of time, anthocyanin degradation often occurs, resulting in color of the fruit turning from bright red to dark reddish-brown (Zhao, 2007). In this study, initial anthocyanin content of fruit from the first and second harvests was 22 mg/100 g fruit fresh weight and 12 mg/100 g fruit fresh weight, respectively. The higher anthocyanin content in fruit from the first harvest compared to the second harvest was most likely due to the fact that strawberries from the first harvest were full red whereas fruit from the second harvest were three-quarter colored when harvested (Figure 5-1). During storage, anthocyanin content of strawberries from the first harvest significantly decreased regardless of the storage temperature (Figure 5-11A). In addition, by the end of the storage period there was no significant difference in the anthocyanin content of fruit stored at different temperatures, most likely due to the advanced over ripeness of the fruit. In fruit from the second harvest, anthocyanin content initially increased, probably due increased synthesis, but then decreased until the end of the storage period (Figure 5-11B). Shin et al. (2008) found total anthocyanins decreased drastically after 9 days when strawberries were stored at 10°C, while Laurin et al. (2004) found that strawberries showed a dramatic decrease in total anthocyanin after 20 hours of exposure to 20°C, while at 0°C the decrease was minor.

Total phenolic content

Total phenolics comprise a large group of antioxidant compounds found in fruits and vegetables (Zhao, 2007). They are synthesized by the plants to protect against pathogen and parasite attack and are usually found in higher amounts in green fruit, giving a characteristic astringent mouth sensation (Zhao, 2007). Some of the phenolic compounds, such as the anthocyanins, also contribute to the coloration of fruits (Zhao, 2007). Lately, they have been intensively studied due to their good antioxidant capacity, which makes then good scavengers of oxygen free radicals in the human body that lead to aging and certain degenerative diseases such as cancer (Zhao, 2007).

In this study, total phenolic content of fruit from the second harvest was higher (198 mg/100 g fruit fresh weight) than in fruit from the first harvest 186 mg/100 g fruit fresh weight), most likely because fruit from the first harvest had developed more red color than those from the second harvest. During storage, phenolic content tended to decrease regardless of the storage temperature (Figure 5-12). However, by the end of the storage period, strawberries stored at 21°C had the lowest levels of phenolics, whereas strawberries stored at 0°C had the highest level of phenolics. Shin et al., (2008) reported similar results with strawberries having less total phenolics (difference of about 1000 mg kg^{-1}) after 9 days of storage at 10°C than at 3°C.

Limiting Quality Factors and Shelf life

Overall, the shelf life of 'Albion' strawberries was relatively short regardless of the storage temperature, most likely related to the initial quality of the fruit at harvest. This was most likely due to the fact that the 2008-2009 strawberry seasons in Florida were greatly affected by the unusual weather conditions (cold and rainy days). Strawberries plants require warm and dry days in order to produce good yield and good quality fruit. This Florida strawberry season (November 2008 to April 2009) was affected by very cold days and copious rain, which affected the yield, reduced the length of the season of harvest, and produced fruit with a lower overall quality. Therefore, we should consider that these conditions represented the worst case scenario for a strawberry season. In addition to the bad weather conditions, fruit from the first harvest were already too ripe compared to fruit from the second harvest, which led to further reduction in their shelf life. In fact, Nunes et al. (2006) reported that 'Chandler', 'Oso Grande', and 'Sweet Charlie' strawberries stored for 8 days at 1°C lasted longer in terms of color and firmness changes when harvested at three-quarters colored stage as opposed to harvested full red.

Fruit from the first harvest had a maximum shelf life of 3.5 days when stored at 1, 6, 10 or 15°C and a maximum shelf life of 3 days when stored at 21°C due to the development of an objectionable reddish-brown color that limited the shelf life of the fruit. Fruit from the second harvest had a maximum shelf life of 5, 4, 3.5, 3 and 2 days when stored at 1, 6, 10, 15 or 21°C, respectively. Color was considered the limiting quality factor for fruit stored at 1°C, whereas shriveling limited the shelf life of strawberries stored at 6°C. Development of objectionable color and shriveling limited the shelf life of fruit stored at 10 or 21°C, while development of objectionable color and softening were simultaneously the major quality limiting factors for fruit stored at 15°C.

Conclusion

'Albion' strawberries from the first harvest had lower acidity, higher SSC, sugar, AA, anthocyanins and phenolic content compared to fruit from the second harvest, most likely because fruit were harvested slightly redder. However, overall quality of the strawberries from the first harvest deteriorated faster than that of fruit from the second harvest, even when stored at 1°C. Storage temperature had a significant effect on the shelf life and overall sensory and compositional quality of ‘Albion’ strawberries. In general, the higher the storage temperature the faster the deterioration of the strawberry fruit, regardless of the season of harvest. Strawberries stored at 6, 10, 15 or 21°C were less red and more reddish-brown, softer and more shriveled, and had higher weight loss and lower acidity, SSC, sugar, AA, anthocyanin and phenolic contents than those stored at 1°C. Storage at 21°C resulted in fruit with poor quality and very short shelf life (2 to 3 days), while storage at 1°C resulted in fruit with best overall quality and longer shelf life (5 days). Results from this study reinforce the importance of harvesting the fruit three-quarter colored rather than full red as well as handling strawberries at constant low temperatures (1°C) and reducing transit time from the field to the store in order to provide the consumer with best quality and maximum remaining shelf life.

Table 5-1. Quality ratings and description for strawberry.

Quality attributes	Method used	Rating and description 1	2	3[a]	4	5	Reference
Color	Visual	Three-quarter colored to full red	Fully light red	Fully dark red	Very dark red (overripe)	Brownish-/purplish (extremely overripe)	Miszczak et al., 1995
Firmness	Tactile by gentle pressure	Extremely soft, deteriorated	Soft and leaky	Minor signs of softness	Firm	Very firm and turgid	Nunes et.al., 2003
Shriveling	Visual	Fresh/turgid fruit and calyx (field fresh)	Minor signs of shriveling, slightly wilted calyx	Shriveling evident, evident signs of moisture loss on fruit/calyx	Severe shriveling, fruit are shriveled and calyx is wilted/dry	Extremely wilted and dry, not acceptable under normal conditions	Nunes et al., 2003
Decay	Visual	0% decay	1-25% decay (brown/gray sunken minor spots)	26-50% decay; slight (spots with decay, some mycelium growth)	51-75% decay; moderate to severe	76-100% decay; severe to extreme (partial or completely rotten)	Nunes et al., 2002
Taste	Gustative	Very poor (unpleasant taste, off-taste, fermented, musty, earthy, very sour, bitter)	Poor (fermented, unpleasant taste)	Acceptable (slightly less intense strawberry taste, may taste slightly earthy)	Good (fresh and sweet taste, less crisp than harvest)	Excellent (pleasant strawberry taste, very sweet, juicy, and crisp)	Nunes et al., 2002
Aroma	Olfactory	Very poor (unpleasant aroma, off-flavor, fermented, musty aroma)	Poor	Acceptable	Good	Excellent (characteristic strawberry odor)	Nunes et al., 2002

[a] Rating of 3 is considered the limit of acceptability before strawberry becomes unmarketable.

Table 5-2. Coefficients of linear correlation (*r*) for subjective firmness with analytical firmness measurements for 'Albion' strawberries during storage of at different temperatures.

Temperature (°C)	First harvest[a]	Second harvest[a]
0	0.819**	0.802**
5	0.870***	0.684ns
10	0.921**	0.880**
15	0.824*	0.803ns
20	0.946**	0.942*

[a]ns, *, **, ***significant differences at P< 0.05, 0.01 and 0.001 levels, respectively, using Pearson's correlation coefficient.

Table 5-3. Coefficients of linear correlation (*r*) for soluble solids content (SSC) with total sugar content for 'Albion' strawberries during storage of at different temperatures.

Temperature (°C)	First harvest[a]	Second harvest[a]
0	0.986***	0.890**
5	0.989***	0.919**
10	0.971***	0.989***
15	0.899**	0.991***
20	0.962**	1.000*

[a]ns, *, **, ***significant differences at P< 0.05, 0.01 and 0.001 levels, respectively, using Pearson's correlation coefficient.

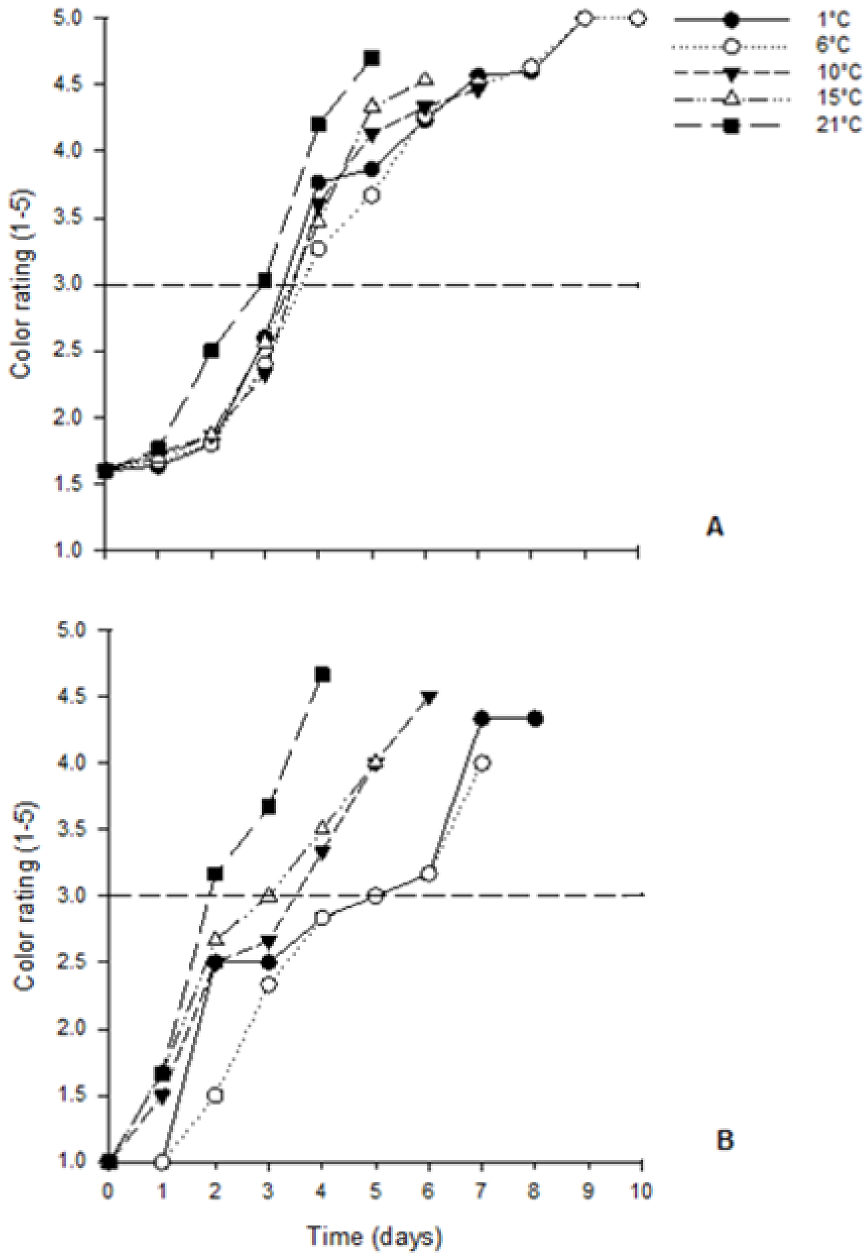

Figure 5-1. Visual color of 'Albion' strawberries during storage at different temperatures. Dotted line represents the limit of acceptability for sale. A) First harvest, $LSD_{0.05} = 0.116$. B) Second harvest, $LSD_{0.05} = 0.140$.

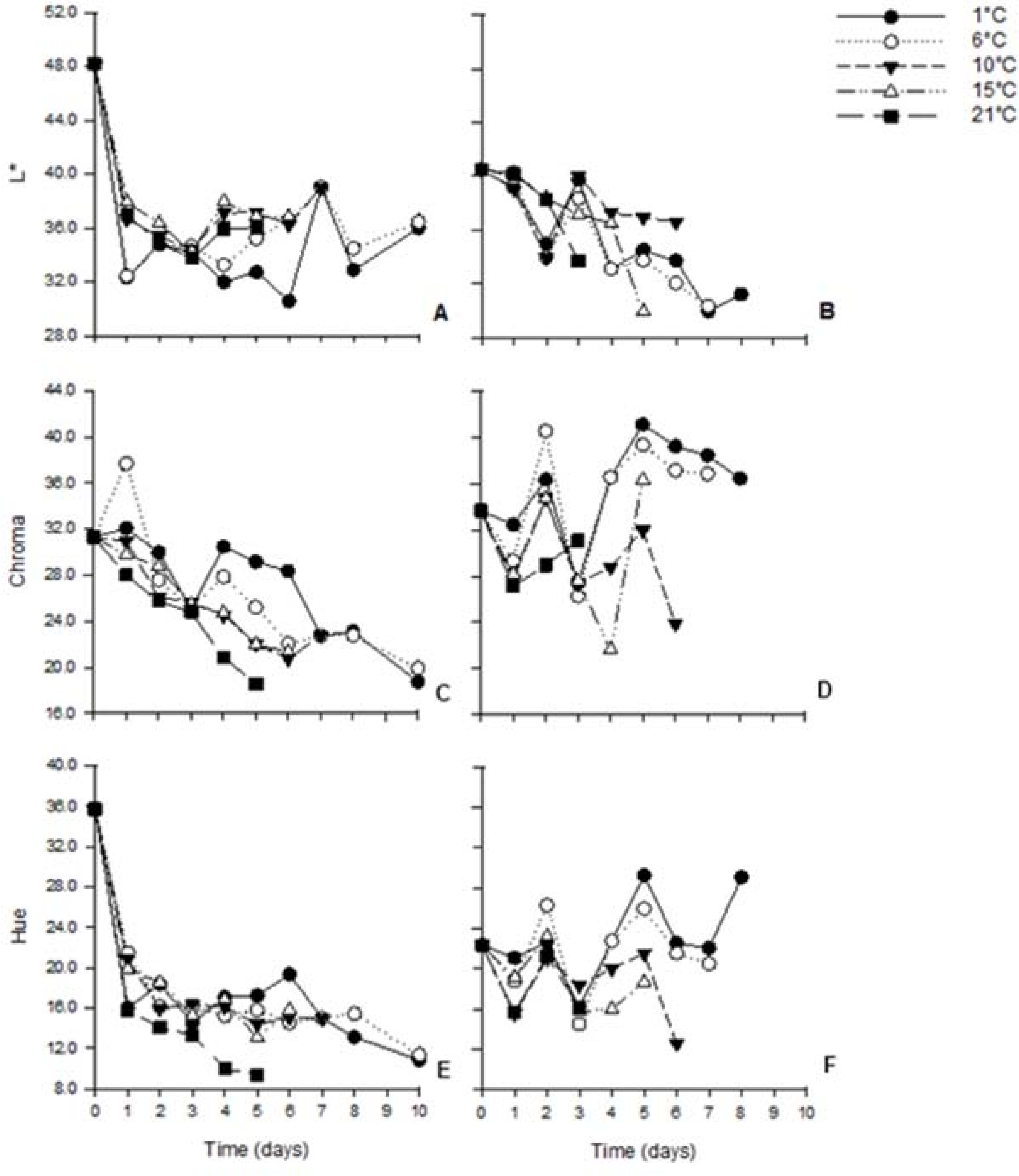

Figure 5-2. L*, chroma, and hue values of 'Albion' strawberries during storage at different temperatures. A) First harvest, $LSD_{0.05}$ = 1.011. B) Second harvest, $LSD_{0.05}$ = 1.038. C) First harvest, $LSD_{0.05}$ = 2.127. D) Second harvest, $LSD_{0.05}$ = 2.143. E) First harvest, $LSD_{0.05}$ = 1.311. F) Second harvest, $LSD_{0.05}$ = 1.344.

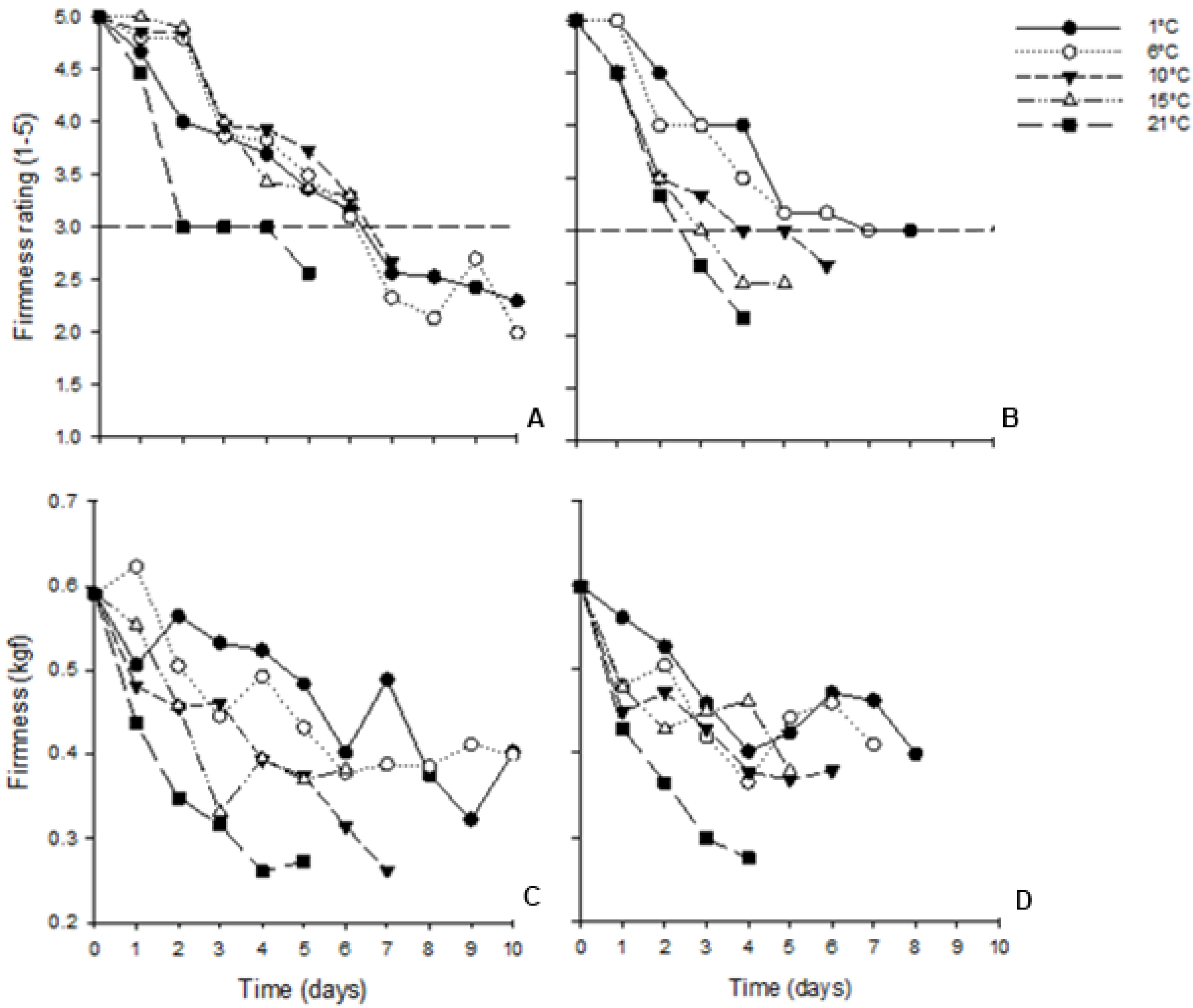

Figure 5-3. Subjective (top) and instrumental (bottom) firmness of 'Albion' strawberries during storage at different temperatures. Dotted line represents the limit of acceptability for sale. A) First harvest, $LSD_{0.05}$ = 0.098. B) Second harvest, $LSD_{0.05}$ = 0.085. C) First harvest, $LSD_{0.05}$ = 0.050. D) Second harvest, $LSD_{0.05}$ = 0.038.

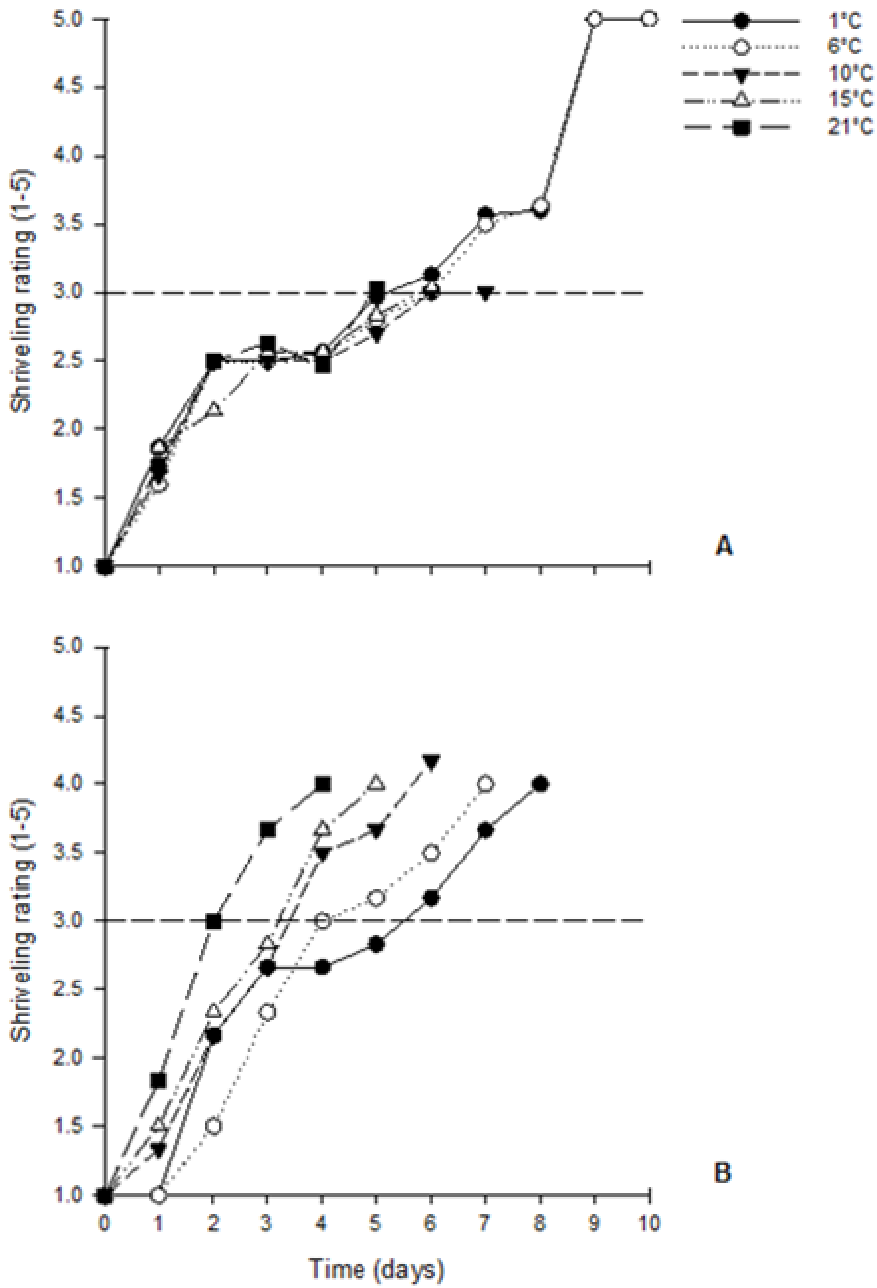

Figure 5-4. Shriveling of 'Albion' strawberries during storage at different temperatures. Dotted line represents the limit of acceptability for sale. A) First harvest, $LSD_{0.05} = 0.065$. B) Second harvest, $LSD_{0.05} = 0.180$.

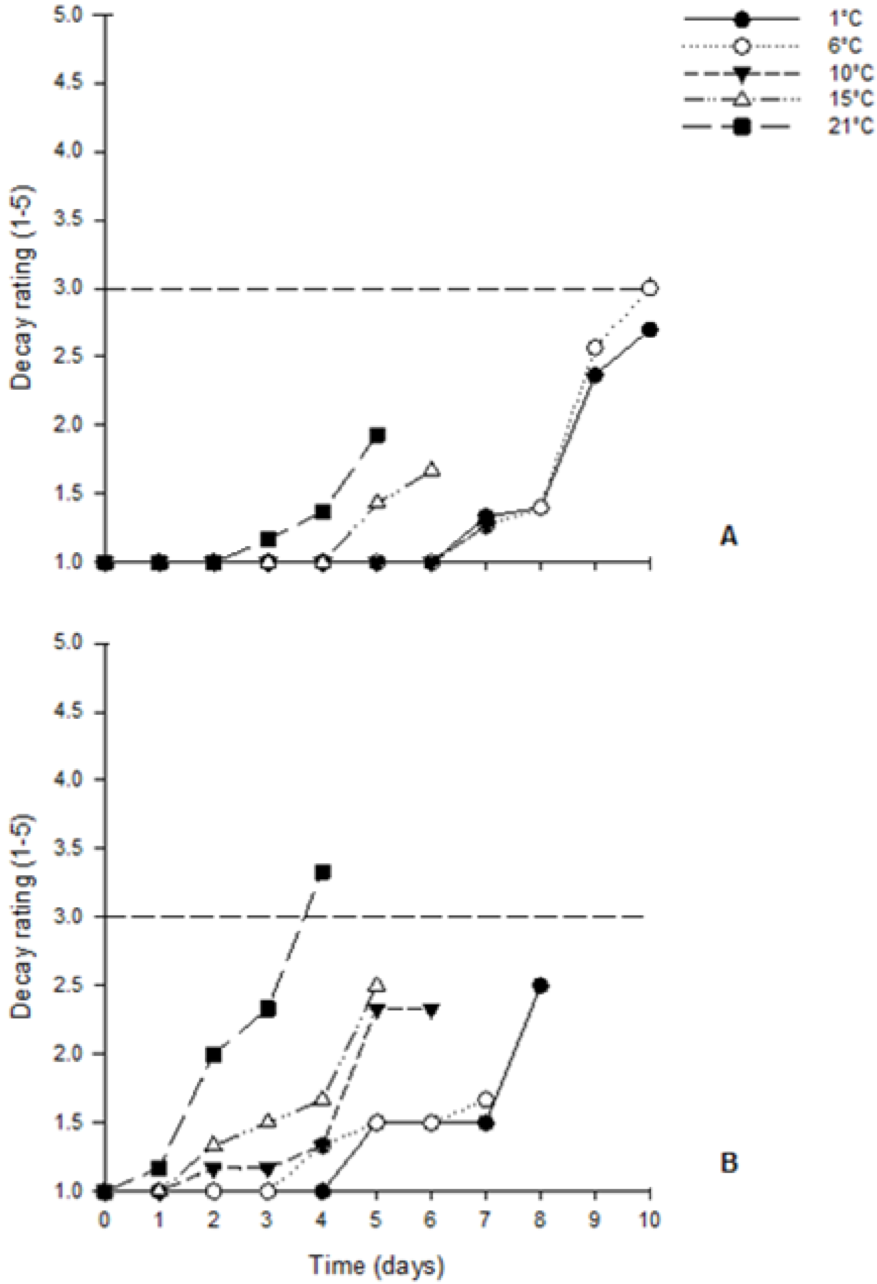

Figure 5-5. Decay of 'Albion' strawberries during storage at different temperatures. Dotted line represents the limit of acceptability for sale. A) First harvest, $LSD_{0.05} = 0.086$. B) Second harvest, $LSD_{0.05} = 0.220$.

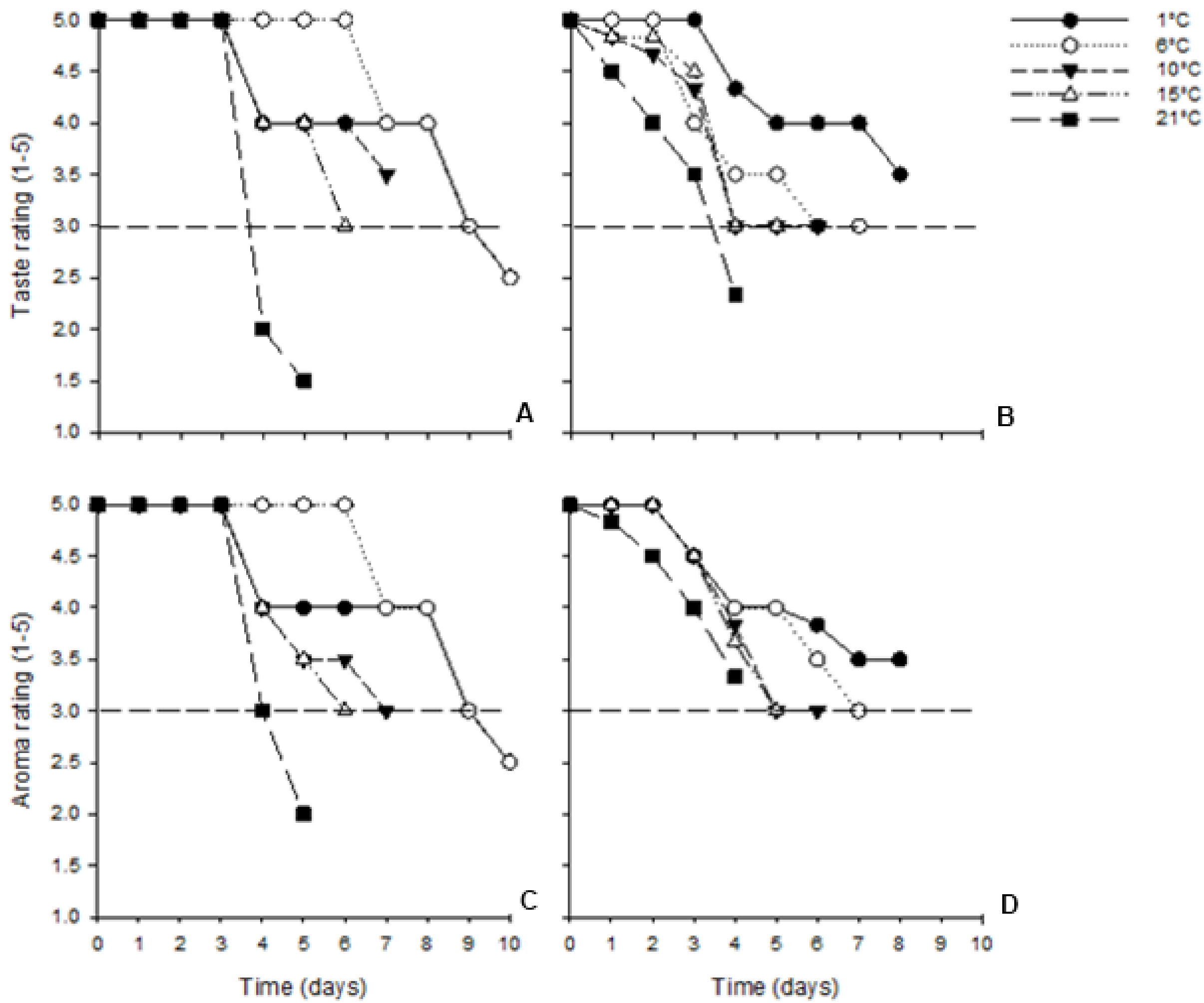

Figure 5-6. Taste and aroma of 'Albion' strawberries during storage at different temperatures. Dotted line represents the limit of acceptability for sale. A) First harvest, $LSD_{0.05}$ = 0.000. B) Second harvest, $LSD_{0.05}$ = 0.134. C) First harvest, $LSD_{0.05}$ = 0.000. D) Second harvest, $LSD_{0.05}$ = 0.085.

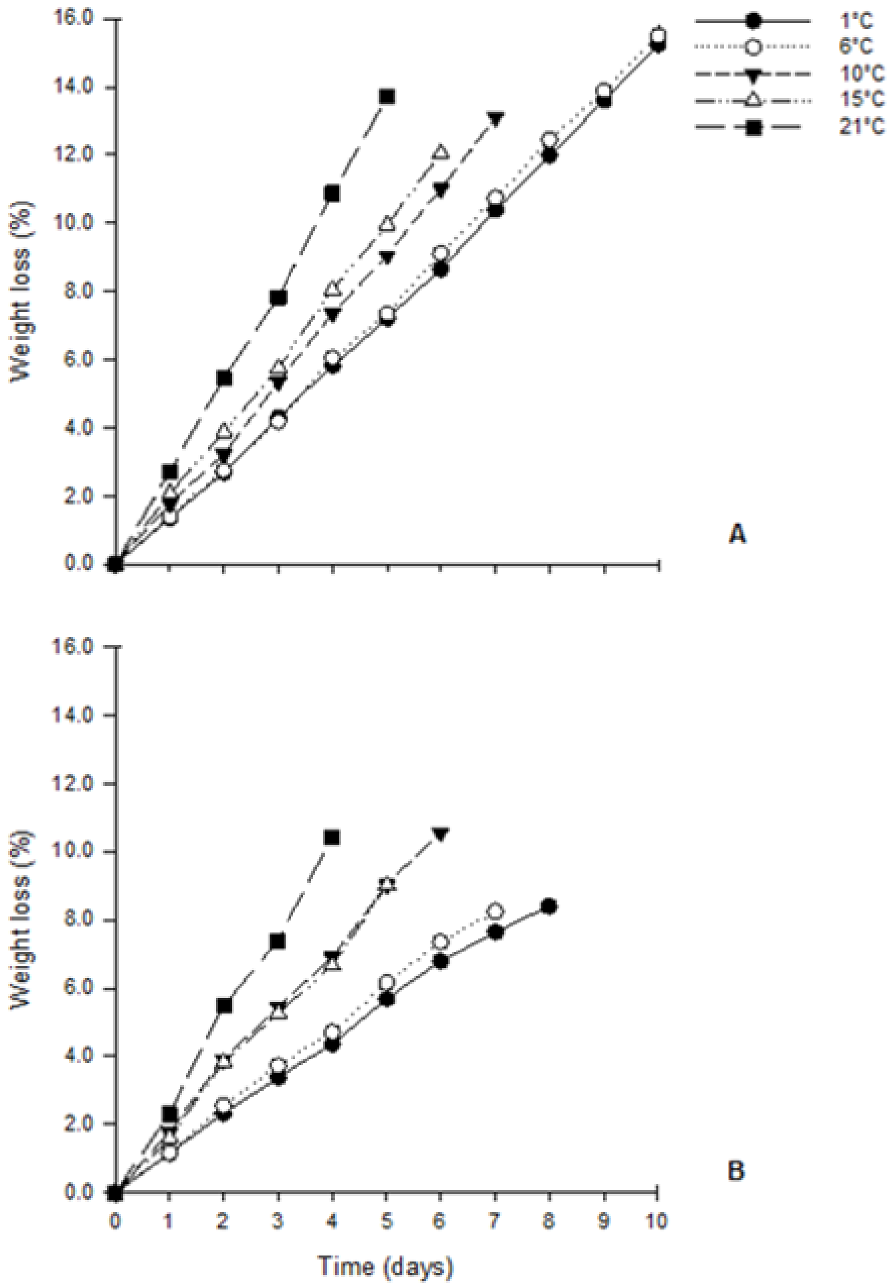

Figure 5-7. Weight loss of 'Albion' strawberries during storage at different temperatures. A) First harvest, $LSD_{0.05} = 0.300$. B) Second harvest, $LSD_{0.05} = 0.356$.

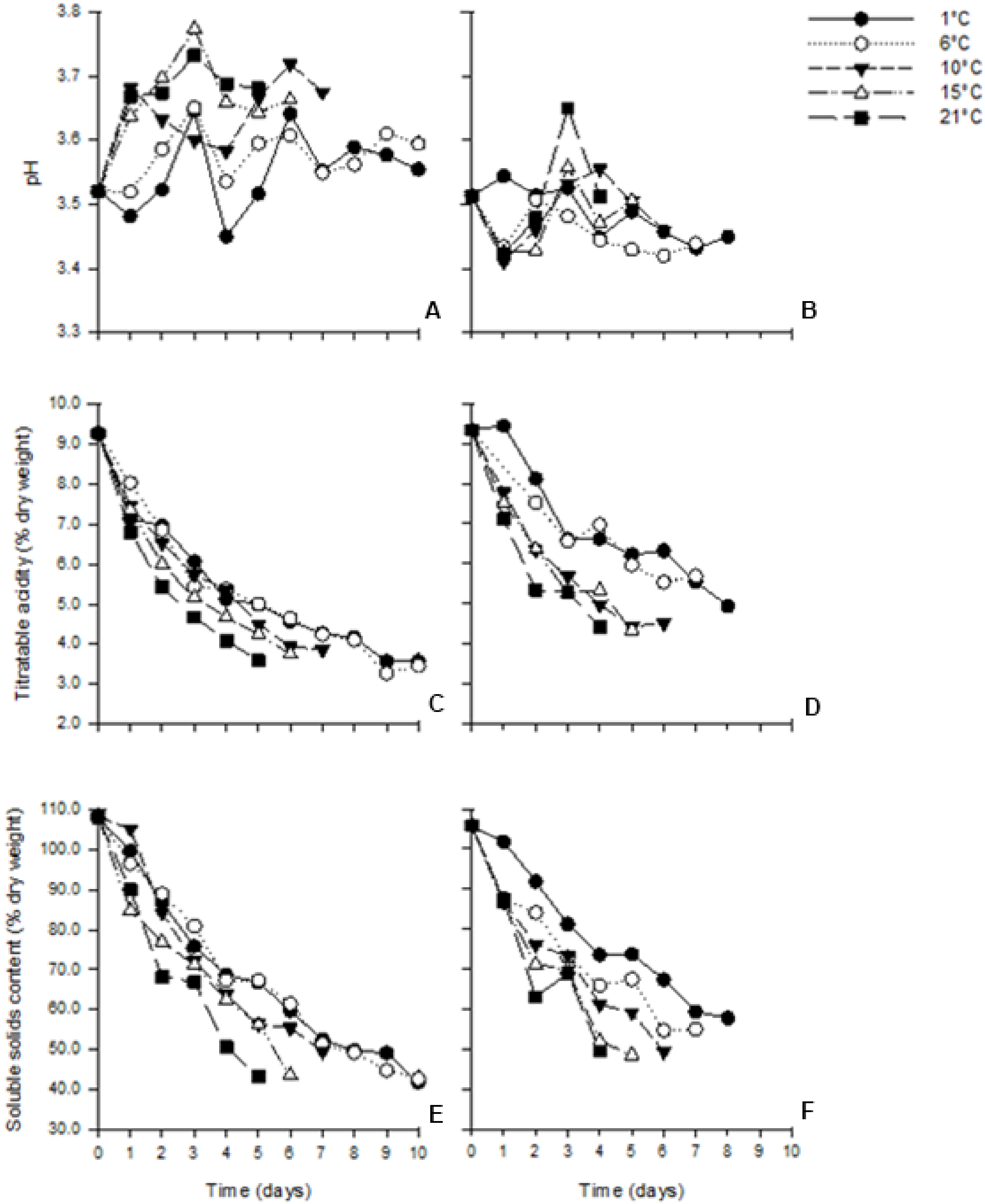

Figure 5-8. pH, titratable acidity (TA), and soluble solids content (SSC) of 'Albion' strawberries during storage at different temperatures. A) First harvest, $LSD_{0.05}$ = 0.014. B) Second harvest, $LSD_{0.05}$ = 0.009. C) First harvest, $LSD_{0.05}$ = 0.127. D) Second harvest, $LSD_{0.05}$ = 0.193. E) First harvest, $LSD_{0.05}$ = 1.278. F) Second harvest, $LSD_{0.05}$ = 1.623.

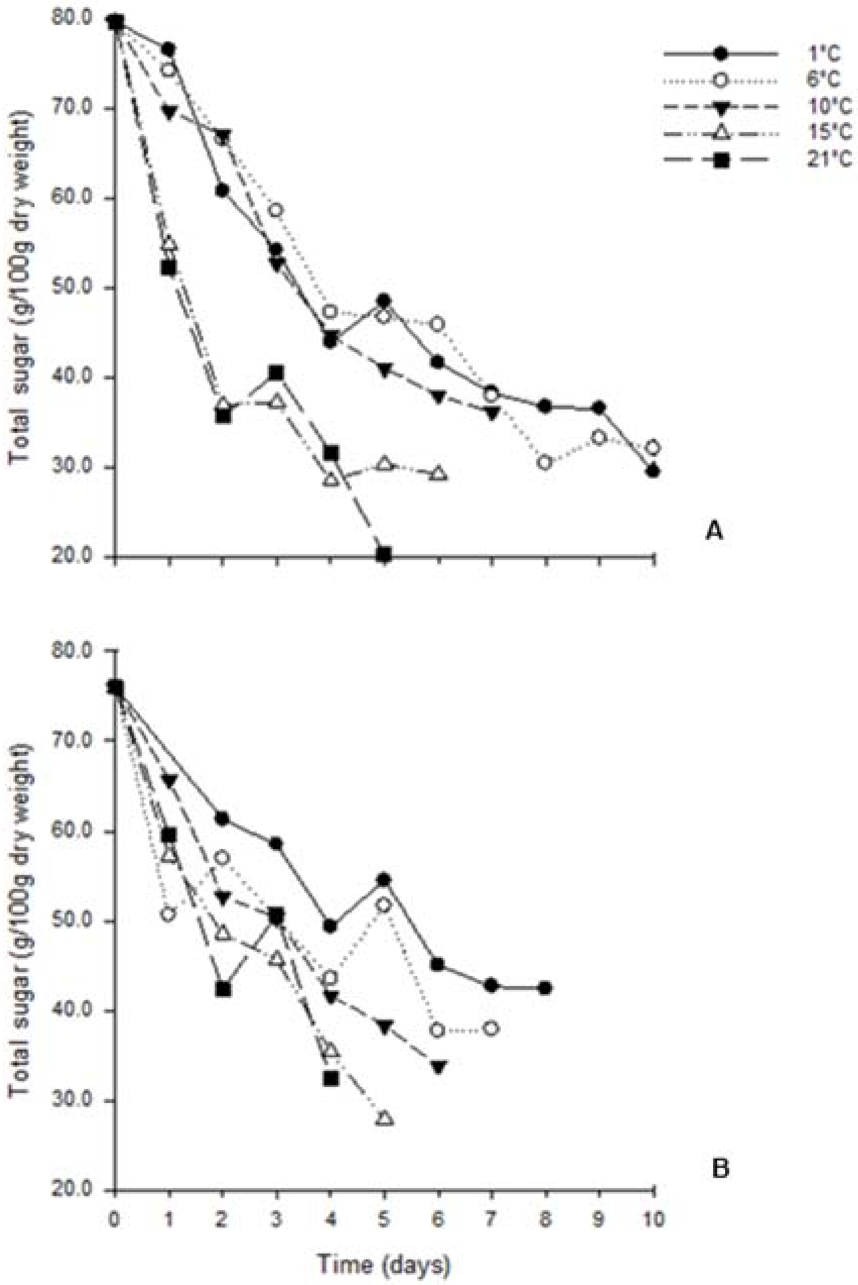

Figure 5-9. Total sugar content of 'Albion' strawberries during storage at different temperatures. A) First harvest, $LSD_{0.05} = 0.570$. B) Second harvest, $LSD_{0.05} = 0.250$.

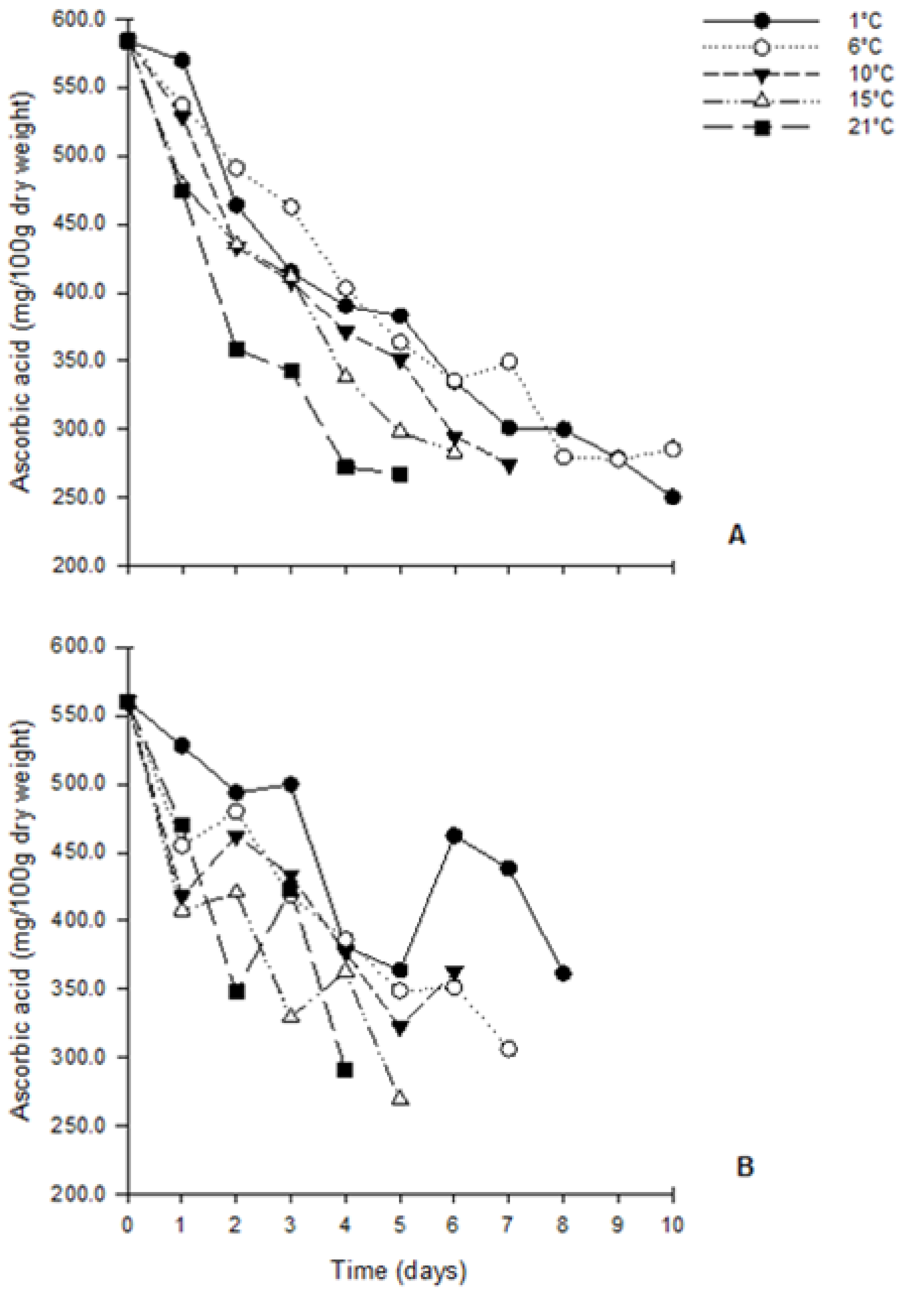

Figure 5-10. Total ascorbic acid content of 'Albion' strawberries during storage at different temperatures. A) First harvest, $LSD_{0.05} = 1.246$. B) Second harvest, $LSD_{0.05} = 1.941$.

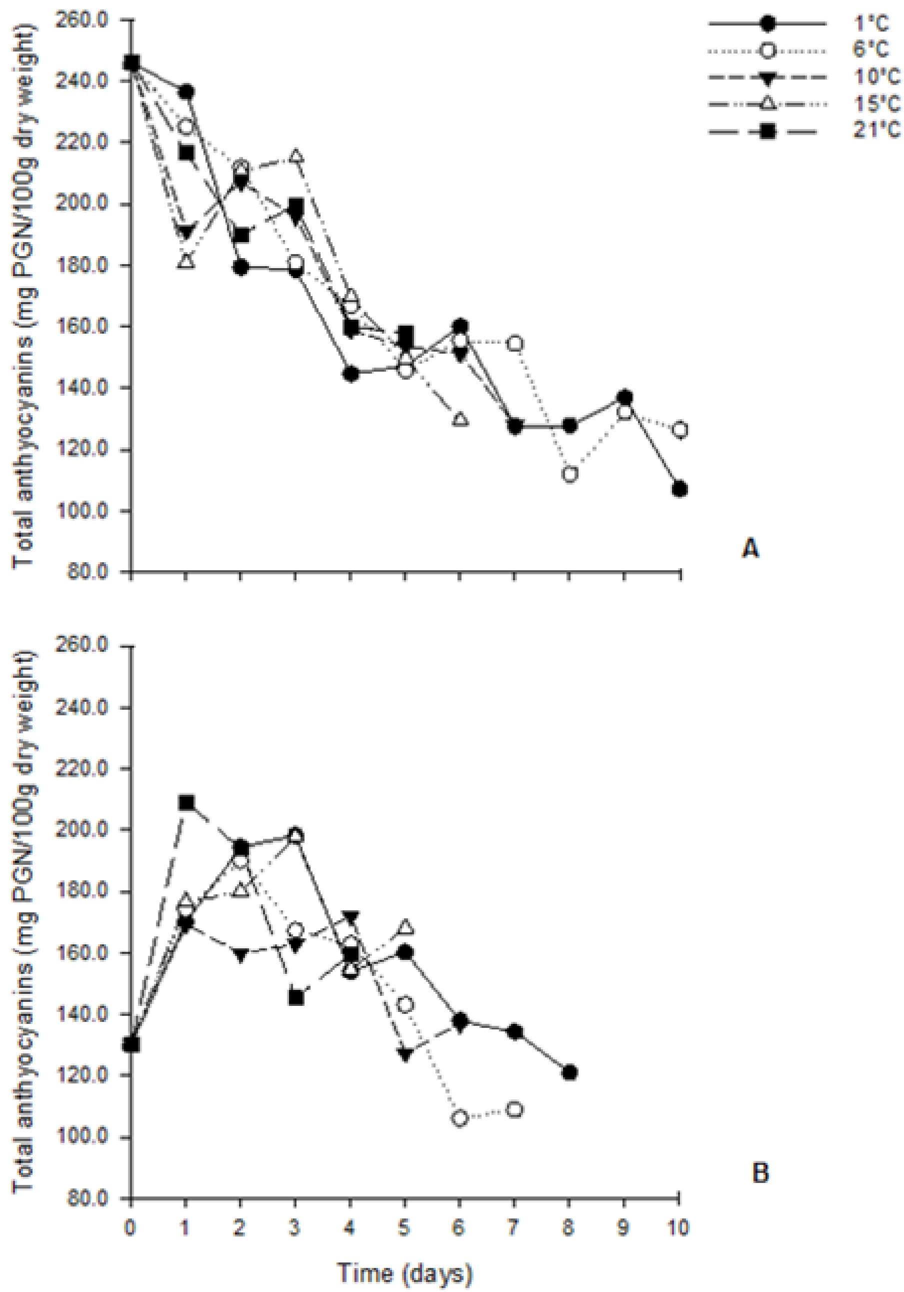

Figure 5-11. Total anthocyanin content of 'Albion' strawberries during storage at different temperatures. A) First harvest, $LSD_{0.05} = 5.478$. B) Second harvest, $LSD_{0.05} = 8.967$.

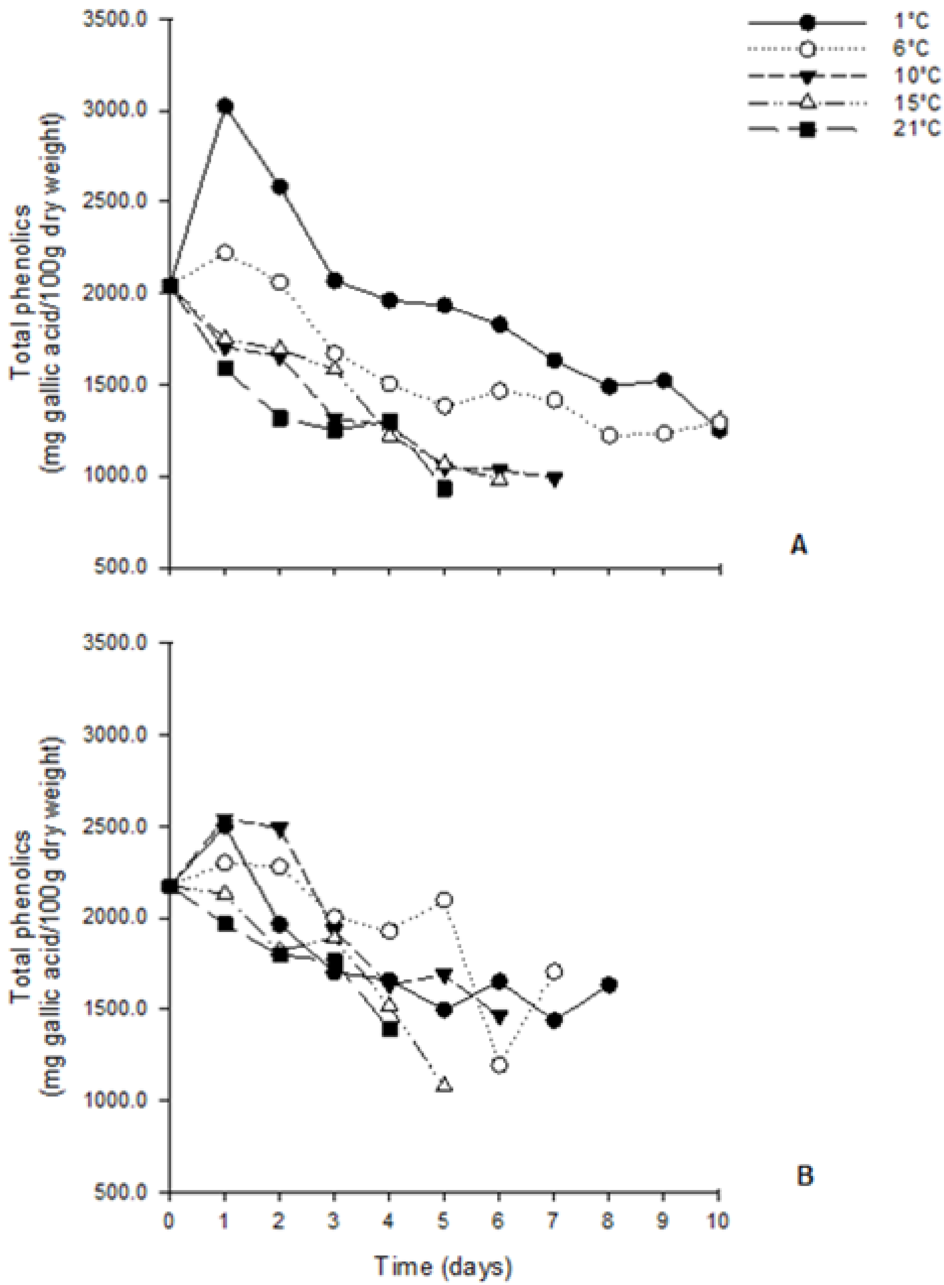

Figure 5-12. Total phenolic content of 'Albion' strawberries during storage at different temperatures. A) First harvest, $LSD_{0.05} = 39.220$. B) Second harvest, $LSD_{0.05} = 67.600$.

CHAPTER 6
CONCLUSIONS, LIMITATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Conclusions

Results from the three studies showed that 'Albion' strawberries are very fragile and have a relatively short shelf life compared to other strawberry cultivars. In addition, the adverse weather conditions experienced during the 2009-2010 Florida season and particularly at the time when the fruit used in these studies were harvested, contributed to an additional reduction in the shelf life of 'Albion' strawberries due to the fair and not excellent quality of the fruit at harvest. For the two last studies conducted in Florida, the temperatures during the studies ranged from -7°C to 33°C with frequent thunderstorms. Cloudy and cool weather delayed ripening of the strawberries and rain prevented harvesting of strawberries on time, which led to over ripening for most of the strawberries. Therefore, during handling of 'Albion' strawberry fruit from the field to the store, proper temperature management, fruit ripeness stage and initial quality, as well as weather conditions at the time of harvest, should all be taken into consideration, as abuse and/or fluctuating temperatures that can be encountered during normal handling operations may result in important losses at the retail level or at consumers' homes.

The first study (field trials) shows that delays before cooling can be too long (5 to 6 hours as observed) and that the entire handling process comprising the time from when the fruit were harvested until delivered to the store can be too long as well (8.8 to 7.2 days as observed). The field study also showed that temperature fluctuations can occur during handling and shipping when strawberry fruit are transferred from one location to another. Consequently, delays before cooling combined with long transit times and fluctuating temperatures encountered during handling of strawberry fruit from the field to the store can contribute to fruit with poor quality and most likely rejection of strawberry loads at the DC and store level if the quality of the strawberries is considered to be below acceptable levels.

The second study (handling simulation) validates the first study and shows that the sensory components important to the overall strawberry quality and marketability (such as color, firmness, and flavor) deteriorate over the period of the handling process, with fruit exposed to fluctuating temperature showing a significantly higher decrease in the sensory quality than fruit from the control treatment, which were maintained constantly at 1°C. Such results can be quantitatively confirmed by the decrease in the compositional attributes of strawberry fruit as seen in the study. Overall, strawberry fruit can have lower acidity and soluble solids content (SSC), lower total sugar, total ascorbic acid, total anthocyanins, and total phenolic contents if exposed to fluctuating temperature as opposed to steady temperature. In order to improve the quality of strawberries, a constant, low storage temperature (0-1°C) should be used throughout the entire handling process from the field to the store with minimal exposure of the fruit to higher temperatures. Small differences in the sensory and compositional quality of strawberries between control and fluctuating treatments towards the end of the handling simulation can be attributed to the advanced ripeness stage of the fruit from the late harvests used in this study. This reinforces the importance of reducing transit times, particularly during late season of harvest and/or during adverse weather conditions, while maintaining an optimum constant temperature during handling of strawberry from the field to the store.

Finally, the shelf life study showed that storage temperature has a significant effect on the shelf life and overall sensory and compositional quality of ‘Albion’ strawberries. In general, the higher the storage temperature the faster the deterioration of the strawberry fruit, regardless of the season/maturity of harvest. Storing strawberries at 6, 10, 15 or 21°C would cause the fruit to be less red and more reddish-brown, softer and more shriveled, and have higher weight loss than those stored at 1°C. Acidity, SSC, total sugar, total ascorbic acid, total anthocyanin, and total phenolic contents would also be lower. Storage at 21°C results in fruit with poor quality and very short shelf life (2 to 3 days), while storage at 1°C results in fruit with best overall quality and longest shelf life (5 days). Some buffer effect exists in that differences between storing at 1 or 6°C were minute compared to storing fruit at 10°C and above. This underscores the effect of storage temperatures of 10 and 15°C being greater than at 1 and 6°C for the strawberry fruit.

Results from this entire study reinforce the importance of harvesting the fruit three-quarter colored rather than full red as well as handling strawberry at constant low temperatures (1°C) and reducing transit time from the field to the store in order to provide the consumer with best quality and maximum remaining shelf life. Growers, shippers and retailers should have more efficient logistic protocols in order to allow strawberries to be transported from the field to the store within the shortest time possible and also avoid fluctuations in temperature from one step to the other on the cold chain.

Limitations and Further Research

Many limitations arose, mostly during the field trials, preventing a more thorough study to be conducted. Field studies are normally very hard to perform and therefore few are reported in the scientific literature. Major limitations include the difficulty in obtaining exact duplications of each handling process from the field to the store. Besides, when quality of the fruit has to be measured on site (i.e., in the field) the type of equipment that can be used is limited to simple portable and powerless devices and/or subjective evaluations of quality (i.e., color, texture, decay, bruising). Problems still arose because these instruments were mostly intended to be used in a typical laboratory setting and not outdoors. For example, refractometers were difficult to use due to the intensity of the sunlight in the field. Balances took longer than usual to stabilize due to the wind and/or unevenness of the ground. Therefore, due to the uncontrollable environmental conditions affecting the instrumentation, adjustments had to be made with most measurements being performed from inside a vehicle. Time was another important limitation because quality measurements need to be taken at a fast pace in order to prevent delays of the normal operations at harvest and at the grower cooling facilities. Thus, only certain quality measurements could be performed within reasonable time.

Therefore, more research is necessary to obtain more thorough and accurate data by having more resources/collaboration available onsite and at each handling process step. The ideal situation would be to have small scale or portable laboratories with similar equipment at each handling process stage where quality of the fruit needed to be measured. Development of basic quality tools and equipment that are easy to calibrate and use under normal ambient conditions (sunlight, wind) would also be needed.

Furthermore, due to invariably long transit times and fluctuating temperatures often encountered during handling, shipping, and at the retail display, additional shelf life studies using different strawberry cultivars would be useful in order to determine the cultivar(s) that would the most suitable for transport from the West to the East coast of the United States or even to export to other countries.

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BIOGRAPHICAL SKETCH

Yun-Pai Lai was born in Taichung, Taiwan. He graduated from the University of Florida with B.S. in food science in 2007. He interned at Checkers Restaurant headquarters in Tampa, FL for the summer of that year. He continued to assist the company with product development throughout his graduate school years. In May 2010, Yun-Pai Lai earned a M.S. degree in food science at the University of Florida with minors in Packaging Science and Horticultural Science.