EFFECTS OF HIGH TUNNEL PRODUCTION ON FLORIDA STRAWBERRY GROWTH, YIELD AND POSTHARVEST QUALITY

By

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The United States is the largest producer of strawberries in the world, with most of them targeted towards the fresh market. Protected strawberry production is widely used in Europe and other parts of the world; however, in California and Florida open-field production remains as the main production system. Strawberry production in high tunnels could potentially increase yield, improve fruit quality, promote early ripening, and reduce rain damage. If adopted in Florida, this technology opens new possibilities for strawberry production practices and eventually increases grower profits by improving winter production and providing fruit early in the season, allowing the advantage of high market prices during winter and early spring.

The objectives of the study were to compare the effects of high tunnel and open-field production on growth, fruit earliness and yield of strawberry cultivars and to evaluate postharvest quality of strawberries. Six treatments were tested using three strawberry cultivars and two production systems. The experimental design was a split-plot design with four and six replications with production systems in the main plots and cultivars in the subplots. Passively-ventilated tunnels were utilized for the study. Strawberry plant diameter and chlorophyll content were determined at 8 and 12 weeks after transplanting and marketable fruit through thirty harvests per season. Fruits per plot were collected to determine color, soluble solids content and

marketability of each treatment at harvest and after 8 days of storage at 7.2^{o}C. During 2007-08 season, vitamin C content, acidity, pH and fruit firmness were also measured.

Strawberry plants grown inside the high tunnel were 18% and 19% than plants in the open field at 8 weeks and 12 weeks after transplant for 2007-08 season. Early yields were 59% and 16% and total yields were 64% and 50% higher inside the high tunnels compared with open field for 2007-08 and 2008-09 seasons, respectively. Production systems had significant effects on marketable fruit percentage and soluble solids for 'Winter Dawn' and 'Florida Elyana', with higher marketability and higher soluble solids from inside the high tunnels. For 'Strawberry Festival' the production systems had no effects on fruit marketability after storage in both seasons.

CHAPTER 1
INTRODUCTION

The commercially grown strawberry (*Fragaria x annanasa* Duch.) is a natural hybrid between two American species: *F. chiloensis* and *F. virginiana* (NASGA, 1982). It is a perennial woody plant composed of a compressed stem or stems (crowns) from which leaves, runners, roots, and inflorescences emerge. The structure typically thought of as the fruit is an aggregate of single-seeded fruits know as achenes, which are located on the outside of a red fleshy receptacle (Darnell, 2003). This fruit crop is widely spread around the world and it can be found in countries from the Arctic to the tropics (Childers, 1980).

The United States is the largest grower of strawberry in the world with an area of 22,300 hectares, followed by Russia and Spain (FAO, 2008). California grows 60% of the strawberry production in the United States (11,330 hectares), followed by Florida with 15% of the planted area (2,850 hectares). The fresh market is the main destination for about 75% of the country's strawberries. However, Florida's strawberries go almost entirely to the fresh market. About 90% of strawberry production in Florida occurs in the west central part of the state, specifically in Hillsborough County (Santos et al., 2007). Hillsborough County has mostly fine, deep sandy soils and production occurs during the dry winter months, when temperatures average 17°C, with maximum and minimum temperatures of 31 and -2 ^{o}C, respectively (FAWN, 2009).

There are two main production systems for strawberry: open-field and protective culture. Protective structures include greenhouses, high tunnels, and mini-tunnels. A greenhouse is a structure with a glass or plastic roof and walls; air warmed mainly by heat from the soil is retained in the building. This characteristic can be beneficial for winter season production and for crops that need high temperatures. On the other hand, during summer the temperature is too hot for many crop plants. Crops inside greenhouses are produced in growing media. Structures

range in size from small sheds to very large buildings. Greenhouses can be high technology production, with automatic equipment such as screens, lights, and heating and cooling systems controlled by computers (Ross, 1994). High tunnels are unheated, plastic covered, solar greenhouses, with passive ventilation through roll-up side walls (Orzolek et al., 2004); height might vary from 2 m to more than 5 m (Blomgren and Frisch, 2007). The crop is grown usually on soil. However, pot, bag and sack culture can be used, along with various growing media (e.g. peat, perlite, pine bark) depending on availability, price and crop. Mini-tunnels or low tunnels are made of galvanized iron bars, with a height of about 50 cm for strawberry. Plants are grown in the soil. Mini-tunnels are covered with clear plastic during cold weather or rain events (Soria-Navarro, 2008b). Open-field production is the main system used in the United States and Australia, while in Europe and Latin America high tunnels, mini-tunnels and greenhouses systems are widely used (Santos et al., 2008).

In Florida and California, strawberry transplants are planted in raised beds, and covered with plastic mulch. The crop is drip irrigated, and safeguarded from frost by using row covers or sprinkler irrigation. However, strawberry production under protected structures might not need the use of sprinkler irrigation for freeze protection. Among the potential benefits of growing strawberries in high tunnels are yield improvement, fruit quality enhancement, reduction of the incidence of insect populations, decreasing weed interference, and protection from rain damage (Chism, 2002; Jett, 2007; Kadir et al., 2006; Ozdemir and Kaska, 1997; Voca et al., 2007). In addition, high tunnels could diminish the effect of cold weather on late fall and winter production. The high tunnel effects on the crop may be due to changes in photosynthetic active radiation (PAR), temperature, air movement, and relative humidity. Photosynthetic organisms use light in a spectral range between 400 and 700 nm, which may influence plant growth.

Temperature affects evapotranspiration, respiration and water absorption. Air movement might affect photosynthesis by affecting air composition, and improve fruit quality by reducing wind velocity. In cucumber, an increase in relative humidity affected leaf elongation, producing larger leaves (Bakker, 1991).

Fresh strawberry is considered one of most perishable fruit crops, for this reason its postharvest quality is an important issue. Quality is defined as 'the degree of excellence or superiority; is a combination of attributes, properties or characteristics that give each commodity value in terms of its intended use' (Kader, 2000). For the wholesale and retail market, appearance, firmness and shelf life are important attributes. On the other hand consumers judge quality by fruit appearance including size, shape, color, glossiness and absence of disease and decay. Quality of strawberry fruit is usually described based on flavor which includes sweetness, acidity, astringency, bitterness, and aroma. Texture is also related to flavor including firmness, crispness and juiciness. Nutritive characteristic including soluble solids content, acidity, vitamin C and anti-oxidants compounds are also considered in this matter (Cordenunsi et al., 2003; Kader, 2000; Sturm et al., 2003). For the purpose of this study, from the wide variety of characteristics mentioned above sweetness, acidity, color, vitamin C, appearance and firmness were selected to be analyzed before and after storage.

In spite of the popular use of high tunnels and protected agriculture in countries such as China, Spain, and Japan, among others (Lamont, 2009), it is still necessary to investigate their effects on Florida strawberry production, due to the differences in climate, cultivars and production systems. Therefore, the objective of this research was to understand the effects of high tunnels on strawberry production, in comparison with open-field production. The null hypotheses of this research were:

a) There is no effect due to production system on plant growth, yield, fruit quality or postharvest shelf life.

b) There is no effect due to cultivar on plant growth, yield, fruit quality or postharvest shelf life.

c) There is no effect due to the interaction between production system and cultivar on plant growth, yield, fruit quality or postharvest shelf life.

CHAPTER 2
LITERATURE REVIEW

Strawberry Description

The strawberry is a small plant that belongs to the Rosaceae family and the *Fragaria* genus. The basic chromosome number for this genus is x=7, there about twenty species of *Fragaria* that can be classified in four groups based on ploidy levels diploid (2n=14), tetraploid (2n=28), hexaploid (2n=42) and octoploid (2n=56). The strawberry commercially grown (*F. x ananassa* Duch) correspond to the octoploid group (Lopez-Aranda, 2008).

The Romans are thought to be the first ones who cultivated strawberries. The wild *Fragaria* species are distributed mainly in three zones: the Americas, Europe, and Asia (Davis, 2008). However, the cultivated strawberry is a widely adapted crop, able to grow in diverse areas. The Food and Agricultural Organization of the United Nations listed 71 countries where strawberries were grown in 2007. The world leaders in strawberry production, based on percentage of the total fruit produced, it is the United States (29%), the Russian Federation (8.5%) and Spain (7%) (FAO, 2008).

Strawberry is a perennial plant which is frequently cultivated as an annual (Galleta and Bringhurst, 1990). Its leaves are trifoliate and are placed helicoidally around the crown (Darrow, 1966), and they usually remain on the plant for one to three months. The root system is formed by 20 to 30 primary roots and hundreds of lateral roots. The roots are mainly superficial with about 90% of them in the first 15 cm of soil (Dana, 1980). Environmental conditions may stimulate the development of leaf axillary buds or branch crowns. These axillary crowns do not have their own roots, and remain attached to the main crown. Runners or stolons are horizontal stems with two nodes, originated from the axillary buds of the crown (Darnell, 2003; Galletta

and Bringhurst, 1990). Strawberry plants propagate by developing runners that produce daughter plants which root into the soil at various distances from the parent plant.

The strawberry inflorescence is a modified stem terminated by a primary flower. Branches emerge at nodes from buds. Each branch is terminated by a flower. Following the primary flower, there are typically two secondary, four tertiary and eight quaternary flowers, and their distribution may vary between cultivars and locations. Flowers generally have five petals and ten green sepals; stamen numbers range from 20 to 35, and pistils from 60 to 600. Primary flowers have more pistils than secondary flowers (Handley, 2003). The true strawberry fruits are the achenes. Each pistil develops into an achene if the one ovary it contains is fertilized. The receptacle is modified stem tissue on to which the achenes are arranged, and is also the edible part of the fruit (Darnell, 2003).

Strawberry cultivars are classified based on how they respond to photoperiod exposure in three categories: Short day or June-bearing cultivars initiate flower buds during short days (i.e. less than 14 h of light). ‘Strawberry Festival’ and ‘Chandler’ are classified as short day types: Long day or ever bearing cultivars initiate flower buds under long days or days with more than 12 hours of light, such as ‘Calypso’ and ‘Evita’ (Burgess, 1997). And finally, day neutral cultivars are insensitive to light with regards to flower initiation and will initiate flowers cyclically; ‘Diamante’ and ‘Aromas’ are examples of this type of cultivar (Darnell, 2003; Chandler and Legard, 2003).

Cultivar Description

'Strawberry Festival' was released by the University of Florida in 2000. This cultivar originated from a 1995 cross between 'Rosa Linda', a high early season yielder with desirable fruit shape, and 'Oso Grande', a University of California cultivar characterized by its ability to produce large, firm fruit (Crocker and Chandler, 2000). 'Strawberry Festival' has a vigorous plant

that tends to produce numerous runners if planted in early October in central Florida. The calyx is large and showy. Its fruit is attached to long pedicels, is medium to large, and mostly conic in shape. The external color of fully mature fruit is deep red and glossy, while internal color is bright red. The fruit has also very firm texture and excellent flavor. 'Strawberry Festival' is susceptible to anthracnose fruit rot (caused by *Colletotrichum acutatum*), Colletotrichum crown rot (caused by *C. gloeosporodies*), and angular leaf spot (caused by *X. fragariae)* (Crocker and Chandler, 2000; Chandler and Legard, 2003). During the 2006-07 season, 'Strawberry Festival' produced 48 t/ha in a central Florida trial (Santos et al., 2007).

'Winter Dawn' is a University of Florida cultivar released in 2005. The seed parent was FL 93-103, and the pollen parent was FL 95-316, both non-patented University of Florida breeding selections (Chandler, C.K., 2009. Patent number US 2009/0013438). It has high early season (November through February) production when planted the last week of September or the first week of October in Florida. It produces medium to large fruit on small plants, and its fruits are moderately resistant to Botrytis and Anthracnose fruit rot diseases when grown in west central Florida or other areas with a similar, subtropical climate (FFSP, 2008). During the 2006-07 season 'Winter Dawn' produced 77 t/ha in a central Florida trial (Santos et al., 2007).

'Florida Elyana' is a strawberry cultivar released by University of Florida in 2008. Originated from FL 96-114 (developed from a cross between 'Sweet Charlie' and 'Cuesta') and FL 95-200 (resulted from the cross of the lines FL 93-46 and FL 93-66, both with pedigree including 'Rosa Linda' and 'Pajaro') (Chandler et al., 2009). It produces fruit from December through March in Florida and these fruit are large, firm, and flavorful. 'Florida Elyana' is moderately resistant to Botrytis fruit rot, and Anthracnose fruit rot (Callies, 2008). Nonetheless, because its fruit are quite susceptible to rain damage, which causes surface cracking, it is only

recommended for protected culture (Chandler and Whidden, 2007). ‘Florida Elyana’ is as productive as ‘Strawberry Festival’ in December and January but not as productive later in the season (Callies, 2008). During the 2006-07 season ‘Florida Elyana’ produced early fruit 19 t/ha and a total yield of 47 t/ha in a central Florida trial (Santos et al, 2007).

Strawberry Production Systems

There are two main production systems for strawberry: open field and under protective structures such as greenhouses, high tunnels and mini-tunnels. In Florida’s open-field production system, strawberries are planted in pre-formed beds, 61 to 71 cm wide and about 20 cm high. Soil is fumigated usually with a mixture of methyl bromide and chloropicrin. Beds are covered with black polyethylene mulch after injection of the fumigant. A small amount up to 50 kg/ha of preplant fertilizer is sometimes used, and is applied broadcast to the soil just before beds are formed. Fertilization and pest control is done according to IFAS (Institute of Food and Agricultural Sciences) recommendations (Peres et al., 2006). Fertigation is applied through a single-drip tape (0.056 L/m/min), and a 15 L/min sprinkler system is used for frost protection and crop establishment. In most cases, bare-root transplants are planted in double rows. After transplanting, overhead irrigation is used for 8 hours for the first 10 days to ensure plant establishment. The high-tunnel production system is in most aspects very similar to the open-field system. Both systems use the same type of beds, soil fumigation, preplant fertilizer, fertigation and pest control, bare-root transplants, and overhead irrigation for plant establishment. The main difference between the systems is that with the high-tunnel system beds are located inside the passively-ventilated structure which is equipped with roll-up side walls managed manually. High tunnels are usually 5 to 10 m wide and 2 m to 5 m tall. The design can be customized to the needs of growers and the available equipment. High tunnels can be built as a single tunnel or as a multi-units (Soria-Navarro, 2008b).

In Florida, the side walls are kept open for most of the season; however, when a freeze is expected the side walls are lowered the day before to help retain heat and maintain the air temperature above 0°C. In this system, sprinklers are used only for crop establishment. In southern California, the main production system is open field. The beds are 152 to 172 cm wide and 36 cm high. Four row beds with 36 cm within row plant spacing is common, which gives a plant density of 76,850 plants per hectare. Plastic mulch is used and two drip lines per bed are installed under the mulch, preplant fertilized is applied broadcast, and liquid fertilizer trough the drip. Sprinkler irrigation is used for crop establishment. Pesticide applications are based on recommendations from University of California Cooperative Extension Service. Strawberry harvest is from January to mid July (Klonsky and De Moura, 2001).

In Spain, all the strawberries areas are produced using protected culture (i.e., mini-tunnels, high tunnels or greenhouses). Strawberry plants are grown in 30 to 35 cm high-raised beds with a top width of 45 to 55 cm and a bottom width of 55 to 65 cm, and covered with plastic mulch. Additional specifications include one drip tape per bed, two rows of plants per bed with a distance between rows of 22 to 28 cm, and a within-row plant spacing of 25 to 35 cm, depending on the vigor of the cultivar. Plant populations range from 50,000 to 70,000 plants/ha. In addition, in some places strawberries are being grown in soilless systems, with a plant density of 100,000 plants per hectare (Soria-Navarro, 2008a).

High Tunnel Effects on Environmental Conditions

Tunnels are considered non-permanent structures because they do not use electricity, heaters or automatic ventilation systems (Panter, 2009). High tunnels can extend the season in cold climates and protect from rain, wind, hail and the occasional freeze in warm areas (Panter, 2009). Temperature differences inside and outside high tunnels can vary between 2 and 17°C (Kadir et al., 2006). Temperatures inside high tunnels are higher during the day, but similar to

the open field during the night (Montero et al., 1985). Nevertheless, the polyethylene plastic cover of the tunnels reduces the photosynthetic active radiation (PAR) by 40% (Santos et al., 2008). In locations with low PAR, there could be insufficient light to reach the minimum required for the plant to develop normally, which might result in lower yields. However, that is not the case in Florida. High tunnels protect the crop from rain, which can result in lower air humidity and soil moisture (Montri and Biernbaum, 2009). Accordingly, high tunnels may also help reduce nutrient leaching (HTVSFPT, 2003). On the other hand, if there is not enough ventilation or if the sides and ends of the high tunnel are closed, temperature and humidity inside the tunnel can increase significantly (Montri and Biernbaum, 2009). The use of high tunnels can enhance the incidence of powdery mildew (caused by *Sphaerotheca macularis*) and two-spotted spider mites (caused by *Tetranychus urticae*) (Demchak, 2004; Pottorff and Panter, 2009). High tunnels might also provide an opportunity to grow crops or cultivars that are sensitive to rain, such as 'Florida Elyana' (Chandler and Whidden, 2007).

Strawberry yields in high tunnels can be as much as 25% greater than those in the open field (Demchak, 2004). High tunnels have the potential to extend the early fall and late spring seasons. This can provide an opportunity to produce ripe fruit when overall fruit production is low and prices are high (HTVSFPT, 2003; Kadir et al., 2006). Fruit produced under high tunnels might have better quality because of protection from rain and wind, which might increase its shelf life (HTVSFPT, 2003; Jett, 2007). Acidity, soluble solids content and vitamin C have been reported to be higher in strawberries from high tunnels compared to those from the open field (Kadir et al., 2006; Voca et al., 2007).

High tunnels are used for a variety of crops. Plants destined for the cut flower industry growing inside high tunnels produce more stems per week than similar plants growing outside

(Wien, 2009). It has been reported that protection from low temperatures allows tunnel-grown plants to start producing up to a month earlier and continue several weeks longer than normal, while the protection from rain helped to maintain flower quality. In California, high tunnels allow raspberries *(Rubus idaeus)* to be produced out-of-season (Gaskell, 2004). Cherries (*Prunus avium*) grown in Michigan under high tunnels produced fruit earlier, with larger size, higher sugar levels and less wind bruising than fruits harvested outside of the high tunnel (Lang, 2009). Moreover, tomato (*Solanum lycopersicum*) harvest in high tunnels in Pennsylvania can begin earlier and last longer than in the open-field, increasing the wholesale prices (Orzolek et al., 2002). Also, romaine lettuce (*Lactuca sativa*) grown in high tunnels was cleaner when compared to open field grown lettuce, which requires intense washing (Rader and Karlsson, 2006).

Postharvest Quality

Strawberry is a non-climacteric fruit and must be harvested at full maturity to achieve the maximum quality in relation to color and flavor (Voca et al., 2007). The fruit ripeness at harvest time will influence the quality for the final market. Mature fruit seem to be more susceptible to mechanical damage than immature fruit, and overripe fruit are likely to become soft after harvest (Kader, 1996). The US No. 1 standard for fresh consists of strawberries of one variety or similar varietal characteristics with the calyx attached, firm, not overripe or undeveloped, and free from mold or decay and free from damage caused by dirt, moisture, foreign matter, disease, insects, or mechanical or other means (USDA, 1965). Each fruit has not less than three-fourths of its surface showing a pink or red color, with a minimum diameter of not less than 1.9 cm. The US standard description of fruit quality specifies the appearance that strawberry fruit should have to be marketable, but does not precise the organoleptic characteristics or nutritional value, which usually are the characteristics that the consumer seek. The term quality is a broad term which usually referred to various product attributes including appearance, sensory attributes such as

color, taste, smell and crispness and the nutritive characteristics, such as sugar/acid ratio, quantity of soluble solids, vitamin C, total acids and anti-oxidative compounds (Cordenunsi et al., 2003; Sturm et al., 2003). For the purpose of this study, from the wide variety of characteristics mentioned above, sweetness, acidity, color, vitamin C, appearance and firmness were selected to be analyzed before and after storage for all the treatments.

Levels of total titratable acidity and sweetness are important components of strawberry flavor. At the beginning of the ripening process the sugar/acid ratio is low, which makes the fruit taste sour, but during the ripening process the fruit acids are degraded, the sugar content increases, and the sugar/acid ratio achieves a higher value. Overripe fruits have very low levels of fruit acid and therefore lack the characteristic strawberry flavor (OECD, 2005).Sweetness can be estimated through the soluble solids content. This value is obtained using a refractometer, and the results are reported in ^{o}Brix and express the soluble solids content in the sample. Citric acid is the most abundant organic acid in strawberries, therefore total titratable acidity is measured as citric acid content.

Color can be measured using a hand-held colorimeter, and is expressed as lightness (L*), hue angle, and chroma (C*). Hue is an angle in a color wheel of 360° with 0 representing the hues red-purple, 90° yellow, 180° bluish-green and 270° blue. Chroma (C*) represents the intensity of the hue angle (Nunes et al., 2002). Lightness values describe darkening during storage, which could occur from increase in pigment concentration or oxidative browning reactions. Lightness, hue angle and chroma values together give an objective determination of color, and allow analyzing and comparing different colors without the errors of subjective color determination (McGuire, 1992).

Vitamin C is the most important vitamin in fruits and vegetables for human nutrition, and more than 90% of it is supplied by fruit and vegetables (Lee and Kader, 2000). Vitamin C is measured as percentage of ascorbic acid. An average value of vitamin C content in strawberry is 60 mg/100 g of fruit, values can vary widely among cultivars, studies in Japan has shown values ranging from 15.9 to 114.8 mg/100 g of fruit weight (Sone et al., 1999). Several other factors can affect the vitamin C content in fruits and vegetables, including preharvest conditions such as cultural practices. For example, the higher the intensity of light during the growing season, the greater is vitamin C content in plant tissues. (Lee and Kader, 2000). Postharvest procedures can also affect vitamin C content. Elevated temperatures during storage increase vitamin C losses (Vinokur et al., 2002).

Visual appearance is subjective assessment of calyx appearance, water loss and sheen to rate the overall appearance of the fruit inside each clamshell, to determine the percentage of marketable fruit. Deterioration of strawberries is caused by injuries from harvesting, handling, decay and natural senescence (Kader, 2002). Management of temperatures influence strawberry quality has been reported that strawberries stored in semi-constant temperature had less weight water loss, less shriveling, and less incidence of bruising compared with those stored in fluctuating temperatures (Nunes et al., 2003). There is also a cultivar effect on appearance rating for postharvest quality for strawberries (Plotto and Chandler, 2006).

Firmness of the fruit is determined by an Instron penetrometer to measure individual firmness of the fruit based on the resistant of the flesh to deformation by the probe, values were expressed in Newton (N). Firmness then measure the resistance of the fruit to mechanical damage. Has been reported that strawberries with different maturity stage has different firmness,

strawberries were firmer at 3/4 red maturity level with a mean stress of 0.136N/mm^2 compared with fruit at 4/4 red with a mean stress of 0.098N/mm^2 (Gunness et al., 2009).

Importance of the Study

Florida is the second largest producer of strawberry in United States, and it is the main supplier for the eastern United States and Canada during the winter. With urban development, space for agriculture in the state is shrinking, so there is a pressing need to produce more on the same piece of land or in a smaller area. Protective structures, especially high tunnels and greenhouses are very popular worldwide for strawberry production, and might help to increase the yields and quality of strawberry fruit produced in the U.S. (Kadir et al, 2006). Per capita consumption of strawberry in the U.S. is 2.7 kg per person (USDA,2007), and taking into account its high vitamin C content, amongst other health benefits, this quantity may increase with an appropriate marketing campaign (University of Illinois Extension, 2008).

There have been many reported benefits of using high tunnels on different crops in different locations; however, there is no research available on its application for strawberry in Florida. This study compares the performance of three cultivars, grown in high tunnels and the open field at Balm, Florida, with respect to plant growth, yield, fruit quality and postharvest shelf life.

CHAPTER 3

EFFECTS OF HIGH TUNNEL PRODUCTION ON FLORIDA STRAWBERRY GROWTH, YIELD AND POSTHARVEST QUALITY.

Materials and Methods

This study was conducted from October to March on the 2007-08 and 2008-09 seasons at the Gulf Coast Research and Education Center of the University of Florida, Balm, Florida. The soil used for the experiment is a fine sandy Spodosol with <1.5% organic matter and pH of 7.2. Planting beds were pre-formed with a standard bedder, 71 cm wide at the base, 61 cm wide on the top, and 25 cm high. In September 2007, the soil was fumigated with 392 kg/ha of methyl bromide + chloropicrin (67/33, v/v). After the fumigant injection, beds were covered with black high-density polyethylene mulch. No pre-plant fertilizer was used. Fertilization and pest control was done according to the requirements of the crop (Peres et al., 2006). Fertigation was applied through a single-drip tape line (0.056 L/m/min) buried 5 cm, and the experimental area was equipped with 15 L/min sprinklers for frost protection and crop establishment.

A factorial set of six treatments (three strawberry cultivars x two production systems) were tested. The experimental design was a split-plot design with 4 replications on 2007-08 season and 6 replications on 2008-09 season. Production systems were the main plots, and cultivars were the subplots. The production systems used were high tunnels and open field; and the cultivars were ‘Strawberry Festival’, ‘Winter Dawn’, and ‘Florida Elyana’. Passively ventilated tunnels (5 m high, 8.5 m wide and 91 m long) were utilized for this study (Haygrove Tunnels, Herefordshire, United Kingdom). Bare-root strawberry transplants from nurseries in Canada were planted on 15 October for both seasons, in double rows 38 cm apart, 20 plants per 7.6 m plot. After transplanting, overhead irrigation was used for 8 hours for the first 10 days to ensure plant establishment (the amount of water used was approximately 480,000 L/ha/day).

Strawberry plant diameters and chlorophyll content readings were taken at 8 and 12 weeks following transplanting. Greenness of leaves was measured with a SPAD-502 (Minolta, Ramsey, New Jersey, USA), a numerical SPAD (Soil Plant Analysis Development) unit, ranging from 0 to 80 is calculated by the chlorophyll meter and used to estimate the chlorophyll content. Strawberries with the calyx attached, a minimum of 80 % red, over 10 g in weight, free of mechanical defects, insects or disease were considered marketable. Marketable fruit weight and number were measured, two times per week for a total of 30 harvests during the season. Early yield was considered as the yield from the first 10 harvests, and the total yield included the 30 harvests through the season. After freeze or near freeze events the yield data on the six following harvests was recorder.

Postharvest data was collected with fruit harvested on February 11, 18 and 25, and March 17 and 24 for 2007-08 season. Fruits were harvested at the Gulf Coast Research and Education Center at Balm, Florida, and transported to the Horticultural Sciences Department in Gainesville, and stored overnight in a cooler at 7.2^{o}C to be processed the next day. For season 2008-09, fruits were harvested on January12 and 26, February 9, 18, and 23, and March 16, and processed on site at the Gulf Coast Research and Education Center.

Storage temperatures for strawberries should be close to 0 ^{o}C, with minimum temperature fluctuation to maximize shelf life up to two weeks to allow the fruit to reach the market in good condition (Kader, 2002). In this study strawberry fruits were stored in plastic clamshells in a cooler at 7.2 ^{o}C for eight days. This temperature is notably higher than the recommendation, with the intention to force postharvest decay. Fully red fruits were stored in 946 mL and 473 mL clamshells (Highland Corporation, Inc., Mulberry, Florida, USA) on season 2007-08 and 2008-09, respectively. For 2007-08 season three fruit per treatment were taken and the external color

was measured on both sides of the fruit with a Minolta CR-400 chroma meter (Minolta, Ramsey, New Jersey, USA). Color was expressed as lightness (L*) value, hue angle value and chroma (C*). Then the calyx was cut off, and the firmness (3 mm deformation) of the center 10 mm slice lengthwise was measured on both sides with an Instron 4411 (Instron Corporation, Norwood, Massachusetts, USA), equipped with a 3-mm diameter tip and 5-kg load cell was used, crosshead speed was 0.83 $mm \cdot s^{-1}$. This test measured individual fruit firmness based in the resistance of the tissue to deformation by the probe.

Fruit stored in the clamshells were subjectively assessed for visual appearance as an average of subjective assessment of calyx appearance, water loss and sheen to rate the overall appearance of the fruit inside each clamshell, to determine the percentage of marketable fruit, with the idea of simulating when a consumer buys strawberries at the supermarket. The scale used for marketable attributes ranged from 0% (when there was no marketable fruit), 20%, 40%, 60%, 80% and 100% (when all fruit was marketable as harvest fresh). The percentages represent the percentage of the fruit inside the clamshell that is saleable based on the variables mention above. Simultaneously, six fruit per treatment were frozen before and after storage to be processed at the end of the season. Frozen samples were defrosted at room temperature, blended in a Hamilton Beach Model 908 blender (Proctor-Silex, Inc, Washington, North Carolina, U.S.A.), and centrifuged on a Beckman Model J2-21 centrifuge (Beckman Coulter, Inc., Fullerton, California, U.S.A.). The juice obtained was frozen in 20 ml plastic vials for later evaluations. Analyses made with the juice were replicated 3 times to assure precision. Soluble solids content (°Brix) was measured by Abbe Mark II digital refractometer (Misco Refractometer, Cleveland, Ohio, U.S.A.), using a drop of unfrozen extract. pH and acidity were measured diluting 6 ml of sample on 50 ml of distilled water and stirred with a Metrohm 728

stirrer (Metrohm USA, Inc, Westbury, New York, U.S.A.) and titrated with Titrino 719 S (Metrohm USA, Inc, Westbury, New York, U.S.A.). Total titratable acidity was calculated as citric acid. Vitamin C was measured for three sampling dates, February 18, February 25, and March 24. Vitamin C content was measured using 2 mL of sample and following the AOAC method 43.064 'Vitamin C (ascorbic acid) in vitamin preparation in juices 2,6-dichloroindophenol titrimetric method' (AOAC, 1984).

On 2008-09 season before and after storage color and soluble solids content were measured, three fruits per treatment were taken; the external fruit color was measured as mentioned above. To measure soluble solids content the tip of each fruit (0.5 cm) was cut and the fruit was squeezed, the juice obtained was used for the measurement with a digital hand-held pocket refractometer Model PAL-1 (Atago USA, Inc., Washington, USA). This procedure of measure soluble solids was used because it is a practical form of determination of soluble solids and can be easily replicated in the field and for growers. Fruits stored in the clamshells were assessed to determine marketable fruit using the same criteria than the anterior season.

Collected parametric data were analyzed using Statistix 9 software (Analytical Software, Tallahassee, Florida, USA) general linear model procedure to determine if there were significant differences between production systems and if there were any production system x cultivar interactions. Treatment means were separated using a Fisher's protected LSD test at the 5% significance level. Data with percentage unit was transformed with $\arcsin^{-1}$ and then analyzed. Measurements of pH were transformed to log base before its analysis, and after the statistical analysis the numbers were transformed back to the original units.

Results and Discussion

2007-08 Season

For 2007-08 season the Florida Automated Weather Network (FAWN) report that October started with warm temperatures with minimum of 18 ^{o}C maximum of 34°C (Table 3-1). By the end of November minimum temperatures descend to 4.6 ^{o}C and maximum temperatures around 30 ^{o}C. At the beginning of January (week 12) temperature dropped to -2.6 ^{o}C, afterwards minimum temperatures were in the range of 2 to 11°C, and maximum were around 30 ^{o}C (for daily averages see Appendix A). The data collected from temperature sensors installed inside the high tunnels and in the open field, show a similar pattern, with an average of 1 to 5 ^{o}C difference between the systems. FAWN report five rainfall events with more than 25 mL of rain (January 19 and 23, February12 and 23, March 7).

Plant diameter and chlorophyll content

Production systems and cultivars had significant effects on strawberry plant diameter and chlorophyll content (Table 3-2). However, there were no significant production systems x cultivar interaction effect on these variables. Plants inside high tunnels were 19 and 18% wider than plants growing in the open field at 8 and 12 weeks after transplant, respectively. ‘Strawberry Festival’ had the widest plant diameter with 28 cm and 34 cm, followed by ‘Winter Dawn’ with 23 cm and 30 cm, and ‘Florida Elyana’ with 20 cm and 26 cm at 8 and 12 weeks, respectively. Chlorophyll content was an 8% higher in the high tunnel than in open field at 12 weeks after transplant. ‘Florida Elyana’ had the higher chlorophyll content at 8 weeks with 45.2 SPAD value, followed by ‘Winter Dawn’ and ‘Strawberry Festival’ with SPAD values of 44 and 43, respectively. ‘Florida Elyana’ and ‘Winter Dawn’ had the higher chlorophyll content at 12 weeks after transplant with 43.7 and 43.3 SPAD value, followed by ‘Strawberry Festival’ with 41.3 SPAD value.

Yields

Strawberry yields were significant affected by production systems and cultivars (Table 3-3 and 3-4). However, there were no significant production systems x cultivars effects. Early yields were 59% higher inside the high tunnel compared with the open field. 'Strawberry Festival' had the highest early yield with 2.4 t/ha, followed by 'Winter Dawn' with 1.6 t/ha and 'Florida Elyana' with 1 t/ha. On January 3 (12 WAT) there was a freeze event. During that night temperature outside the high tunnels were recorded as low as -2.6 ^{o}C (Figure 3-1). For the six harvests following this freeze event the yield inside the high tunnel was 74% higher than in the open field. Six harvests after the freeze event 'Strawberry Festival' had the highest yield with 1.5 t/ha, followed by 'Winter Dawn' with 1.3 t/ha, and 'Florida Elyana' with 0.7 t/ha (Table 3-4). Total yields were 64% higher in high tunnels than in the open-field production. 'Strawberry Festival' had the highest production followed by 'Winter Dawn' and 'Florida Elyana' with yields of 12.4 t/ha, 9.4 t/ha and 7.7 t/ha.

Color

There were five storage tests for five harvest times. For the fruit harvested on February 11 (17 WAT), production systems had no significant effect on lightness (L*), chroma and hue angle values, before and after the storage. (Figures 3-2, 3-3, 3-4, 3-5, 3-6, 3-7, 3-8, 3-9 and 3-10). However, cultivars varied significantly in the color of their fruit. 'Strawberry Festival' was lighter than 'Winter Dawn' and 'Florida Elyana' before and after storage, with lightness values of 32.8, 31.5 and 31.3 respectively before storage and values of 34.7, 33.6 and 33.4 after storage. 'Strawberry Festival' and 'Winter Dawn' had higher chroma values than 'Florida Elyana', with values of 41.3, 38.9 and 37.3, respectively. After storage there was no significant difference in chroma among cultivars. 'Strawberry Festival' had a higher hue angle value, than 'Winter Dawn' and 'Florida Elyana', with values of 33.3, 29.9 and 28.2 respectively before storage, and 33.8,

27.9, and 28.6 respectively after storage (Figures 3.7, 3.8 and 3.9). There were no significant production systems x cultivars effects on fruit color.

For the storage test on fruit harvested February 18 (18 WAT), production systems had no significant effect on lightness, chroma and hue angle values, before and after the storage. Values of lightness were 33.5 and 32.5, chroma 36.5 and 35.6, and hue angle values of 29.4 and 29.0, before and after storage, respectively. There was no significant difference among cultivars on lightness values before and after storage. Chroma values before storage were similar and higher on 'Strawberry Festival' and 'Winter Dawn', than 'Florida Elyana' that was also similar to 'Winter Dawn' the values were 38.4, 36.2 and 35.0 for 'Strawberry Festival', 'Winter Dawn' and 'Florida Elyana', respectively. After storage the chroma values were higher in 'Strawberry Festival' followed by 'Winter Dawn' and 'Florida Elyana', with values of 37.4, 34.6 and 34.5, respectively. 'Strawberry Festival' and 'Winter Dawn' had similar and higher hue angle values, followed by 'Florida Elyana' that was also similar to 'Winter Dawn' before storage, and the values were 32.0, 29.1 and 27.2 for 'Strawberry Festival', 'Winter Dawn' and 'Florida Elyana', respectively. After storage the hue angle values were higher in 'Strawberry Festival' followed by 'Winter Dawn' and 'Florida Elyana', with values of 30.8, 27.6 and 28.5, respectively. However, the interaction between production systems and cultivars was not significant.

For lightness values on fruit harvested on February 25 (19 WAT) production systems had significant effect after storage, with values of 32.9 in high tunnels and 34.4 in the open field. There was not significant effect of production systems on lightness before storage, chroma and hue values. Cultivars had a significant effect for lightness before and after storage, chroma before storage, and hue before and after storage. 'Strawberry Festival' and 'Florida Elyana' had a lighter color than 'Winter Dawn', with values of 30.9, 31.2 and 28.3 before storage, and 34.4,

33.9, and 32.6 after storage respectively. ‘Strawberry Festival’ had higher chroma value than ‘Winter Dawn’ and ‘Florida Elyana’ before storage with values of chroma 39.7, 36.7 and 35.6, respectively. However, the interaction between production systems and cultivars was not significant.

Production systems for the storage test on fruit harvested on March 17 (22 WAT) had significant effect on chroma before storage with values of 38.0 for high tunnels and 36.2 in the open field. There was not significant effect on lightness before and after storage, chroma after storage and hue anglevalues before and after the storage, with values of lightness of 32.9 before and 33.8 after storage, chroma of 36.4 after storage, and hue angle values of 28.9 and 30.5, before and after storage respectively. Cultivars had a significant effect on fruit color before and after the storage. ‘Strawberry Festival’ was lighter than ‘Winter Dawn’ and ‘Florida Elyana’ before and after the storage, with values of 34.7, 31.7 and 32.2 before storage and 35.4, 32.9 and 33.0 after storage, respectively. ‘Strawberry Festival’ had higher chroma values than ‘Winter Dawn’ and ‘Florida Elyana’ with values of 40.1, 35.9 and 35.2 before storage, and values of 39.7, 35.1 and 34.3 after storage, respectively. ‘Strawberry Festival’ had higher hue angle values than ‘Winter Dawn’ and ‘Florida Elyana’ with hue angle values of 32.1, 29.5, and 27.9 before storage, and hue angle values of 32.9, 27.3 and 28.5 after storage, respectively. However, the interaction between production systems and cultivars was not significant.

Color measurements on fruit harvested on March 24 (23 WAT) showed no significant effect of the production systems on lightness, chroma and hue angle before and after storage. The average values for lightness, chroma and hue angle were 34.3 and 34.0, 35.5 and 37.0, and 30.0 and 31.1 before and after storage, respectively. Cultivars had significant effects on lightness and chroma values after storage. ‘Strawberry Festival’ and ‘Winter Dawn’ had similar and higher

lightness values, followed by ‘Florida Elyana’ that was also similar to ‘Winter Dawn’ after storage, and the values were 35.8 for ‘Strawberry Festival’, 33.7 for ‘Winter Dawn’ and 32.4 for ‘Florida Elyana’. For chroma ‘Strawberry Festival’ had the higher values, followed by ‘Winter Dawn’ and ‘Florida Elyana’ with values of 40.0, 36.1 and 34.8, respectively. Cultivars had no significant effects on lightness and chroma values before storage, and hue angle values before and after storage, the average values were 34.3 for light before storage, 35.9 for chroma before storage, 29.6 and 31.1 for hue angle before and after storage, respectively. However, the interaction between production systems and cultivars was not significant.

Fruit firmness

Fruit firmness was not significantly different between production systems or among cultivars before and after storage, for the five harvests tested (Figures 3-11, 3-12 and 3-13). Also, there were no significant interaction effects. Fruit harvested on February 11 (17 WAT) the firmness average values for 3 mm deformation were 0.62 and 0.74 N before and after the storage. The firmness average values for fruit harvested on February 18 (18 WAT) were 0.79 and 0.86 N before and after storage. Fruit harvested on February 25 (19 WAT) had firmness average values of 0.49 and 0.61 N before and after storage. Firmness on fruit harvested on March 17 (22 WAT) average values of 0.72 and 0.81 N before and after storage. Fruit harvested on March24 (23 WAT) firmness average values were 0.65 and 0.79 N before and after storage, respectively.

Marketable fruit

The marketable fruit evaluation after 8 days storage was done within cultivar on both systems. For ‘Strawberry Festival’ the system had significant effects on all the harvests after 8 days storage (Figure 3-14). For the harvest on February 18 (18 WAT) the clamshells from open field had 50% of marketable fruit compared with a 60% marketable fruit inside the high tunnel after the storage. On February 25 (19 WAT) open field had 60% of marketable fruit after storage

compared with 45% marketable from high tunnel. On March 17 (22 WAT) fruit from open field was 60% marketable after storage, meanwhile, there was 50% marketable fruit from inside the high tunnel. On March 23 (23 WAT) fruit from open field was 60% marketable after storage in contrast with 40% from the high tunnel.

For 'Winter Dawn' the production systems had significant effects after storage on the fruit harvested on February 25 and March 17, the clamshells from inside the high tunnel had 50% and 40 % marketable fruit compared with 40% and 50% marketable fruit in open-field, respectively (Figure 3-15). Production systems had significant effects on marketable fruit after storage for 'Florida Elyana' fruit harvested on February 25 and March 17, inside the high tunnel the marketable fruit was 60% and 60% in comparison with 40% and 50% in open field for both dates, respectively (Figure 3-16).

Soluble solids

Soluble solids content varied significantly among cultivars for fruit harvested on February 11 (17 WAT), both before and after storage. However, production system had no effects on soluble solids content, and the interaction between factors was not significant. Before and after storage 'Florida Elyana' had the highest soluble solids content followed by 'Strawberry Festival' and 'Winter Dawn' (Figures 3.-17, 3-18 and 3-19).

Fruit harvested on February 18 (18 WAT) illustrate significant effects of cultivars on soluble solids content after storage. Nevertheless, production systems had not effects on soluble solids content, and the interaction between factors was significant for soluble solids content after storage. 'Florida Elyana' had the uppermost soluble solids content with 8.4^{o}Brix followed by 'Strawberry Festival' with 6.5 ^{o}Brix and 'Winter Dawn' with 5.5 ^{o}Brix before storage. After storage 'Florida Elyana' fruit from inside the high tunnel had the highest soluble solids content with 7.9 ^{o}Brix, followed by 'Strawberry Festival' and 'Florida Elyana' in the open field, with

values of 7.2 and 7.1 ^{o}Brix, then ‘Strawberry Festival’ and ‘Florida Elyana’ inside the high tunnel, with values of 6.3 and 6.0 ^{o}Brix, ‘Winter Dawn’ in the open field had the lowest soluble solids content with 5.4 ^{o}Brix.

Production systems had significant effects soluble solids content for fruit harvested on February 25 (19 WAT) after storage. Cultivars had effects on fruit soluble solids content before and after storage. However, the interaction between both factors was no significant. Fruit produced in open field had higher soluble solids content after storage than fruit from inside the high tunnel, with values of 5.3 and 4.8 ^{o}Brix. ‘Florida Elyana’ had the higher soluble solids content followed by ‘Strawberry Festival’, and ‘Winter Dawn’ had the lowest soluble solids content, with values of 5.9, 5.1 and 4.2 ^{o}Brix before storage and soluble solids content of 5.9, 4.9 and 4.3^{o}Brix after storage.

Cultivars had significant effects on soluble solids content for the fruit harvested on March 17 (22 WAT) before and after storage. However, production system had no significant effects on soluble solids content, and the interaction between both factors was no significant. Before storage ‘Florida Elyana’ had the maximum soluble solids content, followed by ‘Strawberry Festival’ and ‘Winter Dawn’ with values of 8.4, 6.5 and 5.6 ^{o}Brix, respectively. After storage ‘Florida Elyana’ had the highest soluble solids content with 8.2 ^{o}Brix, followed by ‘Strawberry Festival’ and ‘Winter Dawn’ with soluble solids content of 6.3 and 6.2, respectively.

Interaction among production systems and cultivars was significant for soluble solids content on fruit harvested March 24 (23 WAT) before storage. After storage cultivars had significant effects on soluble solids content and production system had no effects. Before storage ‘Florida Elyana’ in open field and inside the tunnel and ‘Winter Dawn’ in open field had the highest soluble solids content with values of 7.6, 6.9 and 7.4 ^{o}Brix, correspondingly, ‘Winter

Dawn' inside the tunnel had the lowest soluble solids content with 5.3 ^{o}Brix. After storage 'Florida Elyana' had the highest soluble solids content with 6.9 ^{o}Brix followed by 'Strawberry Festival' and 'Winter Dawn' with 5.7 and 5.3 ^{o}Brix.

Total titratable acidity

Production systems had significant effects on total titratable acidity (expressed as citric acid) measured on strawberry before and after the storage for fruit harvested on February 11 (17 WAT). The interaction between production systems and cultivars was not significant (Figures 3-20, 3-21 and 3-22). Citric acid content on fruit inside the high tunnel was 15% superior compared with fruit in the open field before storage, on fruit after storage de citric acid content was 24% higher inside the high tunnel than open field.

Cultivars had significant effects on fruit acidity before and after storage for fruit harvested on February 18 (18 WAT). However, the interaction between production systems and cultivars was no significant. 'Strawberry Festival' and 'Winter Dawn' were similar and had the greater citric acid content followed by 'Florida Elyana' with values of 0.71, 0.72 and 0.61% citric acid before storage and 0.75, 0.77 and 0.63% citric acid after storage, respectively.

Before storage cultivars had significant effects on acidity content for fruit harvested on February 25 (19 WAT), although, the interaction between production systems and cultivars was no significant. After storage, the interaction between both factors was significant. Before storage 'Strawberry Festival' and 'Winter Dawn' had higher acidity than 'Florida Elyana' with 0.72, 0.72 and 0.57 % citric acid, respectively. After storage the greater citric acid content was found on 'Winter Dawn' in the high tunnel and in the open field, 'Strawberry Festival' in the high tunnel and in the open field with values 0.81, 0.73, 0.76 and 0.79% citric acid, and 'Florida Elyana' had the lowest citric content inside the high tunnel and in open field with 0.64 and 0.72 % citric acid.

For fruit harvested on March 17 (22 WAT) cultivars had significant effects on strawberry fruit citric acid content after storage. However, the interaction between production systems and cultivars was not significant before and after storage. Before storage, the average citric acid content on strawberry fruit was 0.80% citric acid. After storage 'Winter Dawn' had 0.88% citric acid followed by 'Strawberry Festival' and 'Florida Elyana' with 0.79 and 0.74 % citric acid.

Production system had significant effects on citric acid content after storage for fruit harvested on March 24 (23 WAT). Cultivars had significant effects on citric acid content before and after storage. However, the interaction between both factors was no significant. Inside the tunnel the citric acid content was 26% lower than in open field after storage. 'Winter Dawn' had higher citric acid content than 'Strawberry Festival' and 'Florida Elyana' with 0.74, 0.66 and 0.65 % citric acid before storage, and 0.91, 0.70 and 0.69 % citric acid after storage. For the five storage tests pH was also measured before and after storage, but there was not a clear trends on the results (see appendix B)

Vitamin C

Vitamin C content for fruit harvested on February 11(17 WAT) was affected by production systems and cultivars before storage, there was no interaction between both factors. After storage the interaction among both factors was significant for vitamin C content (Figures 3-23, 3-24, and 3-25). Before storage the vitamin C content on fruit inside the high tunnel was 13% higher than in open field. 'Strawberry Festival' and 'Winter Dawn' had the highest vitamin C content with 24.9 and 21.5 mg/100 g, and the lowest content was on 'Florida Elyana' with 16.3 mg/100g. After storage 'Strawberry Festival' inside the high tunnel had a vitamin C content of 18.3 mg/100 g, all the cultivars in open field and 'Winter Dawn' inside the high tunnel were similar with an average content of 13.6 mg/100 g, the lowest vitamin C content was found on 'Florida Elyana' inside the high tunnel 9.2 mg/100 g.

The interaction between production systems and cultivars was significant on fruit harvested on February 25 (19 WAT) for vitamin C content before storage. After storage production systems and cultivars had significant effects on vitamin C content, however, the interaction between both factors was not significant. Before storage ‘Strawberry Festival’ inside the high tunnel and ‘Winter Dawn’ in open field had vitamin C values of 21.3 and 19.8 mg/100 g, the lowest vitamin C values were for ‘Strawberry Festival’ and ‘Florida Elyana’ in open field, and ‘Winter Dawn’ and ‘Florida Elyana’ inside then high tunnel, with of 17.6, 19.8, 19.0 and 18.2 mg/100 g, respectively. After storage the vitamin C content in strawberry fruit produced inside the high tunnel was 22% higher than fruit from open field. ‘Strawberry Festival’ and ‘Winter Dawn’ had higher vitamin C content than ‘Florida Elyana’ with values of 17.2, 16.1 and 14.6 mg/100 g, respectively.

Before and after storage production systems had significant effects on strawberry fruit vitamin C content for fruit harvested on March 24 (23 WAT). Cultivars had significant effects on vitamin C content after storage. However, the interaction between both factors was not significant before and after storage. The vitamin C content of strawberry fruit produced inside the high tunnel was 25% higher than open field before storage, and 15% higher after storage. Before the storage the average vitamin C content was 14.8 mg/100 g. After storage ‘Strawberry Festival’ and ‘Winter Dawn’ were similar and had the highest Vitamin C content with 12.4 and 11.3 mg/100 g, ‘Florida Elyana’ had the lowest vitamin C content 10.5 mg/100 g, and was also similar to ‘Winter Dawn’.

Strawberry plants grown in high tunnel were wider than plants in open-field production. ‘Strawberry Festival’ had the wider plants, followed by ‘Winter Dawn’ and ‘Florida Elyana’. These results confirm that high tunnels promote more growth in the plants than field conditions

(Kadir et al., 2006). Since the PAR inside the tunnel is lower inside the tunnel this might be causing etiolating of the plants, plant elongate trying to reach more light. Chlorophyll content in plant leaves was higher in plant inside the high tunnel compare with the open field. In average 'Florida Elyana' had higher SPAD values than 'Winter Dawn' and 'Strawberry Festival'. SPAD values suggest that plants are growing in a normal range, considering the relation between SPAD value and chlorophyll content for strawberry (r^2=0.92) (Hilmerick et al., 1992)

Yields were higher in the high tunnel compared with the open field. 'Strawberry Festival' had the highest yield followed by 'Winter Dawn' and 'Florida Elyana'. The results obtained in this study correspond with previous research where high tunnel conditions produce early strawberries and marketable fruit was greater inside than outside the high tunnels (Kadir et al., 2006). The increase in the marketable yield is led by the tunnel protection (Lutchoomun and Cangy, 1997). A key advantage of high tunnel production is the exclusion of rainfall, which can detrimentally influence product quality (Montri and Biernbaum, 2009).

Fruit color was not different in high tunnel and open-field production system before and after storage. In average the color of 'Strawberry Festival' was lighter than 'Florida Elyana' and 'Winter Dawn'. Chroma values and hue angle values followed the same pattern. Differences in color were captured by the colorimeter, but they could not be distinguished by comparing fruit side by side under bare eye, which means color could not be used as a variable to compare fruit from both systems. Production systems and cultivars had no effects on strawberry fruit firmness before and after storage this might be due to different ripe stages of the fruit at sample time. Production systems had effects on marketable fruit for 'Florida Elyana' and 'Winter Dawn'. Cultivars had effect on marketable fruit for two of the four storage test.

Production systems had no effects on strawberry fruit soluble solids content before and after the storage. Cultivars had effects on soluble solids content before and after storage. 'Florida Elyana' had the highest soluble solids content followed by 'Strawberry Festival' and Winter Dawn'. The interaction between factors was significant in two out of ten sampling dates.

In general, production systems had little or no effects in strawberry fruit total titratable acidity. Cultivars had effects on fruit total titratable acidity. Production systems had significant effects on fruit vitamin C content; fruit from inside high tunnel had more vitamin C than fruit from open-field. Cultivars had effects on vitamin C content. However there was interaction between both factors on 2 sampling dates, out of six. Previous research on strawberry in high tunnels report highest total titratable acidity and soluble solids content and highest Vitamin C values in high tunnels (Voca et al, 2007). In Balm for the season 2007-08, there were differences between systems only for vitamin C values, with highest values on fruit from high tunnel. There were also differences between cultivars.

2008-09 Season

For 2008-09 season FAWN report that October started with warm temperatures with minimum of 12 ^{o}C maximum of 29°C (Table 3-5), minimum temperature dropped to 1.6^{o}C on the last week of October. November and February minimum temperatures range in average from 0 to 5 ^{o}C and maximum temperatures from 25 to 30°C. March temperatures rise with minimum temperatures reaching 11 ^{o}C and maximum of 31 ^{o}C (for daily averages see Appendix A). During this season three freeze events occur January 21 to 23, February 5 and 21, with minimum temperatures of -3, -5.6, -5, -2.8 and -0.6, respectively. The data collected from temperature sensors installed inside the high tunnels and in the open field, show a similar pattern, with an average of 1 to 5 ^{o}C difference between the systems. FAWN report two rainfall events with more than 25 mL of rain (November 30 and December 11).

Plant diameter and chlorophyll content

Production system had significant effects on strawberry plant diameter and chlorophyll content in leaves at 12 weeks after transplanting (Table 3-6). Strawberry cultivars had effects on strawberry plant diameter and chlorophyll content in leaves at 8 and 12 week after transplant. However the interaction between the two factors was no significant. Plants inside the high tunnel were 10.7% wider than plants in the open field at 12 weeks after transplant. 'Strawberry Festival' had the widest plant diameter at 8 week after transplant with 26 cm, followed by 'Winter Dawn' and 'Florida Elyana' with 23 cm and 22 cm. 'Strawberry Festival' had wider plants 12 weeks after transplant with 35 cm diameter, followed for by 'Winter Dawn' with 27 cm and 'Florida Elyana' with 22 cm. Chlorophyll content was 2.3% higher on strawberry plants inside the high tunnel than in open field at 12 weeks after transplant. 'Florida Elyana' and 'Winter Dawn' had the higher chlorophyll content at 8 weeks after transplant with of 48.5 and 48.5 SPAD value, and followed by 'Strawberry Festival' with 45.2 SPAD value. At 12 weeks after transplant 'Florida Elyana' had the highest chlorophyll content with 50.6 SPAD value, followed by 'Winter Dawn' with 48.7 SPAD value and 'Strawberry Festival' with 46.4 SPAD value.

Yields

On early yields and total yields production systems and cultivars had significant effects. However, the interaction between both factors was not significant (Table 3-7). Early yield inside the high tunnel was a 16% greater than open field. 'Strawberry Festival' had the highest early yield with 3.3 t/ha, followed by 'Winter Dawn' with 2.7 t/ha and 'Florida Elyana' with 2.0 t/ha. Total yield was 50% superior inside the high tunnel compare with open field. 'Strawberry Festival' had the highest total yield 18.6 t/ha, followed by 'Winter Dawn' and 'Florida Elyana' with 9.0 t/ha and 8.4 t/ha, respectively.

During the strawberry season there were three freeze o near to freeze events, January 21 to January 23, February 5 and 21 (Table 3-8), after these freeze events the yield data for the following six harvests was collected. Interaction among production systems and cultivars were significant. After the first freeze event the yield was higher on 'Strawberry Festival' inside the high tunnel with 4.6 t/ha, the lowest yield were in 'Winter Dawn' and 'Florida Elyana' in open field with yields of 0.8 and 1.3 t/ha. After the second freeze 'Strawberry Festival' inside the high tunnel had the highest yield 4.4 t/ha, followed for 'Winter Dawn' inside the high tunnel, 'Florida Elyana' inside the high tunnel and 'Strawberry Festival' in open field with an average of 2.9 t/ha, 'Winter Dawn' in open field and 'Florida Elyana' in open field had the lowest yield after the second freeze with an average of 1.1 t/ha. After the third freeze 'Strawberry Festival' inside the high tunnel had the greater yield with 5.4 t/ha, followed by 'Strawberry Festival' in open field with 3.7 t/ha, the treatments with lowest yield were 'Florida Elyana' and 'Winter Dawn' in open field, with yields of 1.7 and 1.1 t/ha, respectively.

Color

Color measurements were taken to the strawberry fruits before and after the storage test for five harvest times (Figures 3-26, 3-27, 3-28, 3-29, 3-30, 3-31, 3-32, 3-33 and 3-34). For the fruit harvested on January 12 (13 WAT) production systems had significant effects on lightness before storage and chroma before and after storage. Cultivars had significant effects on lightness after storage, chroma before and after storage, and hue angle after storage. However, the interaction between production systems and cultivars was no significant. Fruit from inside the high tunnel had 5.4% lighter color, than fruit from open field before storage, chroma values were 3.9% and 10.4% higher inside the high tunnel before and after storage respectively. Lightness values after storage on 'Strawberry Festival' were similar to 'Winter Dawn' with 33.2 and 32.4, respectively; 'Winter Dawn' was also similar to 'Florida Elyana' with 31.1 lightness value.

Chroma values before storage were higher on ‘Winter Dawn’ and ‘Florida Elyana’ with values of 38.4 and 39.6, followed by ‘Strawberry Festival’ with 34.5 chroma value, after storage ‘Winter Dawn’ and ‘Florida Elyana’ had the highest chroma value 38.1 and 35.8, ‘Strawberry Festival’ was similar to ‘Florida Elyana’ with a 35.0 chroma value. For hue angle value after storage ‘Strawberry Festival’ had 28.7 the highest hue angle value, followed by ‘Winter Dawn’ with 24.8 hue angle value, and ‘Florida Elyana’ with 23.8 hue angle value.

Lightness values on strawberry fruit after storage, and hue angle values before and after storage were significantly affected by production system on fruit harvested on January 26 (15 WAT). Cultivars had significant effects on lightness values before and after storage, chroma values after storage, and hue angle values before and after storage. However, the interaction between both factors was significant only for chroma values before storage. Lightness values on fruit after storage inside the high tunnel were 4.9% greater than fruit in open field, hue angle values were 4.9% superior before storage and 7.2% higher after storage in fruit from inside the high tunnel compared with fruit from open field. ‘Winter Dawn’ had 35.6 lightness value before storage, followed by ‘Strawberry Festival’ and ‘Florida Elyana’ with 34.0 and 33.7 lightness values. After storage the peak lightness value was founded on ‘Winter Dawn’ and ‘Strawberry Festival’ with 34.6 and 33.6 lightness value, respectively, ‘Florida Elyana’ was similar to ‘Strawberry Festival’ with 33.0 lightness value. Chroma values after storage was higher on ‘Winter Dawn’ with 41.5, followed by ‘Florida Elyana’ with 39.7, and ‘Strawberry Festival’ with 34.9 hue angle value. ‘Strawberry Festival’ had the greater hue angle value before and after storage with values of 29.0 and 29.1, followed by ‘Winter Dawn’ and ‘Florida Elyana’ with averages of 25.7 and 25.2 before and after storage, respectively. Chroma before storage was the highest on ‘Winter Dawn’ in open field with 43.1 chroma value, followed by ‘Florida Elyana’ in

open field, ‘Winter Dawn’ inside the high tunnel, and ‘Florida Elyana’ inside the high tunnel, with an average value of 39.9 chroma, the lowest values were for ‘Strawberry Festival’ in both inside the high tunnel and open field, with 35.3 average chroma value.

On February 9 (17 WAT) there was not enough fruit on the ‘Winter Dawn’ plots on both systems, and therefore the analysis included only ‘Strawberry Festival’ and ‘Florida Elyana’ inside the high tunnels and in open field. Production systems had significant effects on hue angle values after storage; and cultivars had significant effects on chroma and hue angle values after storage. Interaction between both factors was significant for chroma and hue values before storage. Production systems had no significant effects on lightness values. Before storage the average lightness value was 35.5 and after storage the average lightness value was 33.2. The hue angle value after storage was 0.8% greater in fruits from inside the high tunnels compared with the open field. ‘Strawberry Festival’ had 36.3 chroma value after storage, lower than ‘Florida Elyana’ with 37.5 chroma value. ‘Strawberry Festival’ had a 19.3% higher hue angle value than ‘Florida Elyana’. Chroma values before storage were the highest on ‘Florida Elyana’ in open field with 40.8 value, followed by ‘Strawberry Festival’ in open field and ‘Strawberry Festival’ inside the high tunnel with values of 38.0 and 36.5 respectively, ‘Florida Elyana’ inside the high tunnel had a 35.7 chroma value that was similar to ‘Strawberry Festival’ under the same system. ‘Strawberry Festival’ inside the high tunnel and in open field had the greater hue values with 30.1 and 28.4, respectively. ‘Florida Elyana’ in open field had a 27.8 hue angle value and was similar to ‘Strawberry Festival’ in the same system; the lowest hue angle value was 25.8 found in ‘Florida Elyana’ inside the high tunnel.

For fruit harvested on February 23 (19 WAT), production systems had significant effects on lightness and hue angle values after storage. Cultivars had significant effect on lightness after

storage, chroma before and after storage, and hue angle after storage, and the interaction between both factors had significant effects only on lightness and hue angle before storage. The fruit from inside the high tunnel was 6.1% lighter after storage than fruit from open field. Hue angle values inside the high tunnel were 8.1% greater than in open field. 'Strawberry Festival' and 'Winter Dawn' had the highest lightness value after storage averaging 34.3 lightness value, followed by 'Florida Elyana' with 32.8 lightness value. 'Florida Elyana' and 'Winter Dawn' had the highest chroma value before storage with an average of 39.8 chroma value, followed by 'Strawberry Festival' with 36.4 chroma value. After storage 'Winter Dawn' had the highest chroma value 39.4, followed by 'Strawberry Festival' and 'Florida Elyana' with 35.5 and 36.9, respectively. Hue angle value after storage was higher on 'Strawberry Festival' with 31.1, followed by 'Winter Dawn' and 'Florida Elyana' with average of 25.5 hue value. The highest values for lightness before storage were founded on 'Strawberry Festival' and 'Winter Dawn' inside the high tunnel with 37.2 and 36.9 lightness values, respectively, the lowest values were founded on 'Florida Elyana' and 'Strawberry Festival' in open field, with 33.9 and 33.0 lightness values. For hue angle values before storage the highest value was founded on 'Strawberry Festival' with 33.2 hue angle value, and the lowest values were for 'Winter Dawn' and 'Florida Elyana' inside the high tunnel and in open-field, with 26.4 average hue angle value.

Production systems had significant effects on lightness, chroma and hue angle after storage for strawberry fruit harvested on March 16 (22 WAT). Cultivars had significant effects on lightness, chroma and hue angle, before and after storage. However, the interaction between both factors was no significant. The lightness value on fruits from inside the high tunnel after storage was 34.0 compared with 33.3 in open field. Fruit from inside the high tunnel after storage had a 4.7% greater chroma value than open field, with 37.4 and 35.7, respectively. Hue angle values

after storage were 8.4% superior inside the high tunnel than open field. ‘Florida Elyana’ had the highest lightness value before storage with 34.9 followed by ‘Strawberry Festival’ and ‘Winter Dawn’ with 33.3 and 32.9 lightness values. After storage lightness value was the highest in ‘Winter Dawn’ with 33.2, but that value was also similar to ‘Strawberry Festival’ and ‘Florida Elyana’ with 32.2 average lightness value. For chroma the top values were founded in ‘Winter Dawn’ and ‘Florida Elyana’ with values of 37.0 and 38.1 before storage, and 38.5 and 38.6 after storage, followed by ‘Strawberry Festival’ with chroma values of 32.4 before storage and 32.6 after storage. Hue angle values were higher on ‘Strawberry Festival’ with 28.5 hue angle value before storage and 31.1 after storage, followed by ‘Florida Elyana’ with 26.8 hue angle value before storage and 27.1 after storage, and then ‘Winter Dawn’ with 23.2 hue angle value before storage and 24.4 after storage.

Marketable fruit

For the marketable fruit evaluation after storage the analysis was done within cultivar on both systems (Figures 3-35, 3-36 and 3-37), for ‘Strawberry Festival’ the system had significant effects only on fruit harvested on February 9 (17 WAT)after 8 days in storage. Fruit from open field had 60% of marketable fruit compared with a 43% inside the high tunnel. For ‘Winter Dawn’ the system had significant effects after storage on the fruit harvested on February 23 (19 WAT) the clamshells from inside the high tunnel had 43% marketable fruit compared with 23% marketable in fruit from open field. On ‘Florida Elyana’ system had significant effects after storage for fruit harvested on January 12, February 9 (17 WAT) and March 16 (22 WAT), inside the high tunnel the marketable fruit was 67, 63 and 53% compared with 27, 27 and 40% in open field for the three dates, respectively.

Soluble solids

Soluble solids content was measured in fruit before and after the five storage tests at five different harvest times (Figure 3-38, 3-39 and 3-40). For the fruit harvested on January 12 (13 WAT), production systems and cultivars had significant effects on strawberry soluble solids content after storage, and there was an interaction between the factors for the soluble solids content before storage. The soluble solids content of the fruit from inside the high tunnel was 7.5% greater than in the open field after the storage. 'Florida Elyana' had the highest soluble solids content with 8.9 ^{o}Brix after storage, followed by 'Strawberry Festival' with 7.9 ^{o}Brix and 'Winter Dawn' with 7.0 ^{o}Brix. 'Strawberry Festival' in open field, 'Florida Elyana' inside the high tunnel, and 'Strawberry Festival' inside the high tunnel had the highest soluble solids content before storage, with values of 9.7, 9.1 and 9.7 ^{o}Brix. The lowest soluble solids content before the storage was founded on 'Winter Dawn' in open field with 7.1 ^{o}Brix.

Soluble solids content on fruit harvested on January 26 (15 WAT) showed no significant effect of production system before or after storage. Cultivar had significant effect on soluble solids content before and after storage. However, the interaction between both factors was not significant. 'Strawberry Festival' and 'Florida Elyana' had the highest soluble solids content before storage and after storage with an average of 10.1 and 11.0 ^{o}Brix, respectively, than 'Winter Dawn' with 8.8 and 9.5 ^{o}Brix, before and after storage, respectively.

The interaction between productions systems and cultivars was significant before and after the storage on fruit harvested on February 9 (17 WAT) (there was not fruit from the 'Winter Dawn' plots for this harvest). Before storage 'Florida Elyana' grown inside the high tunnel had the greater soluble solids content 13.3 ^{o}Brix, followed by 'Florida Elyana' grown in open field, 'Strawberry Festival' grown in open field, 'Strawberry Festival' grown inside the high tunnel with values between 10.4 and 11.2 ^{o}Brix. After storage 'Florida Elyana' inside the high tunnel

had the highest soluble solids content with 13.4 ^{o}Brix, followed by ‘Strawberry Festival’ in open field, ‘Strawberry Festival’ inside the high tunnel and ‘Florida Elyana’ in open-field with values from 10.6 to 11.6 ^{o}Brix.

Before and after storage the interaction between production systems and cultivars was significant on soluble solids content for fruit harvested on February 23 (19 WAT). Before storage ‘Florida Elyana’ inside the high tunnel had 13.1 ^{o}Brix, followed by ‘Strawberry Festival’ inside the high tunnel with 10.6 ^{o}Brix, then ‘Winter Dawn’ inside the high tunnel, ‘Florida Elyana’ in open field and ‘Strawberry Festival’ in open field with an average of 9.5 ^{o}Brix, the lowest soluble solids content before storage was 7.4 ^{o}Brix in ‘Winter Dawn’ in open field. After storage ‘Florida Elyana’ inside the high tunnel had the greater soluble solids content 12.4 ^{o}Brix, and the lowest value was found on ‘Winter Dawn’ in open field.

Cultivar and production systems had significant effect on soluble solids content for the fruit harvested on March 16 (22 WAT) before and after storage. However, the interaction between both factors was not significant. Soluble solids content on fruit from inside of the high tunnel was superior than fruit from open field, the values inside the high tunnel were 19.0% and 19.5% greater than open-field before and after storage, respectively. ‘Florida Elyana’ had the highest soluble solids content before and after storage with values of 10.7 and 10.3 ^{o}Brix, followed by ‘Strawberry Festival’ and ‘Winter Dawn’, with averages of 8.5 and 7.7 ^{o}Brix before and after storage, respectively.

Strawberry plants grown inside the high tunnel were wider than plants grown in open field. ‘Strawberry Festival’ had wider plants, followed by ‘Winter Dawn’ and ‘Florida Elyana’. Chlorophyll content in strawberry leaves were similar o higher on plants inside the high tunnel than in open field. ‘

Fruit harvested at different times (13, 15, 17 and 19 weeks) was stored for 8 days at 7.2^{o}C, and were later analyzed for a number of variables. Soluble solids content of these samples was higher in fruit from inside the tunnel compared with open field fruit. 'Florida Elyana' had the highest soluble solids content, followed by 'Strawberry Festival' and 'Winter Dawn'. Chroma values were higher in 'Winter Dawn' followed by 'Florida Elyana' and 'Strawberry Festival' for both systems, before and after storage. Hue angle values were greater on 'Strawberry Festival' followed by 'Florida Elyana' and 'Winter Dawn' for both systems, before and after storage. Marketable fruit after storage was similar or higher inside the high tunnel for 'Florida Elyana' and 'Winter Dawn' than in open field, for 'Strawberry Festival' the fruit from inside the tunnel was similar or had less marketable fruit after storage than in open field.

In conclusion there were significant effects when strawberries were cultivated inside high tunnel at the Researcher Center (Balm, FL). Plants were wider, and produce more fruit in all the cultivars tested, as reported in other studies (Kadir et al., 2006; Lutchoomun and Cangy, 2008). Fruit inside the tunnel for the freeze event was protected from low temperatures and wind; and there was not damage on plant or fruit after the cold event inside the tunnel. No water was used inside the tunnel to prevent freeze compared with the ten nights of water used for open-field production (in average in one night of sprinkler frost protection 627,000 liter per hectare of water are used), which suggests that implementation of high tunnels might improve water use efficiency while keeping good quality production. For the postharvest study fruit from inside the tunnels had higher soluble solids content, and for two of the cultivars the marketability after storage inside the tunnel was similar or better than in open field. However, more research needs to be done for other cultivars, and other locations. An economical analysis is needed to determine if the cost-benefit of the implementation of this practice for growers.

Table 3-1. Data from temperature sensors located in open-field and high tunnel at 10 cm height, and temperature from FAWN weather report, for Balm during 2007-08 season.

Date	Week	Tunnel			Open-field			FAWN		
		Temperature (^oC)								
		Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
17-Oct-07	Week 1	N/A	N/A	N/A	N/A	N/A	N/A	25.0	17.9	33.5
24-Oct-07	Week 2	N/A	N/A	N/A	N/A	N/A	N/A	23.7	17.7	32.8
31-Oct-07	Week 3	N/A	N/A	N/A	N/A	N/A	N/A	21.9	9.3	29.3
07-Nov-07	Week 4	18.0	7.8	29.1	17.7	7.4	28.7	16.2	5.6	26.9
14-Nov-07	Week 5	18.6	7.4	29.5	18.4	6.6	29.1	17.3	4.6	28.1
21-Nov-07	Week 6	21.7	12.6	31.1	21.4	12.2	31.1	20.1	11.6	29.2
28-Nov-07	Week 7	21.2	9.0	31.9	20.8	8.6	31.1	21.4	15.4	30.3
05-Dec-07	Week 8	20.8	7.8	31.9	20.5	6.2	31.1	18.4	4.3	29.4
12-Dec-07	Week 9	19.3	3.7	33.2	18.8	2.9	31.5	21.6	8.4	29.8
19-Dec-07	Week 10	19.3	11.4	31.5	18.2	9.8	27.9	15.2	2.3	26.2
26-Dec-07	Week 11	21.6	10.2	33.2	20.9	9.4	31.1	19.8	11.9	28.8
02-Jan-08	Week 12	14.9	-0.6	31.5	13.5	-1.1	28.7	13.5	-2.6	26.2
09-Jan-08	Week 13	19.3	5.4	33.2	18.0	2.9	29.9	19.5	9.4	28.5
18-Jan-08	Week 14	18.5	10.6	24.4	17.2	4.2	28.7	15.5	2.8	27.1
25-Jan-08	Week 15	N/A	N/A	N/A	15.2	3.7	28.7	16.5	4.6	27.1
01-Feb-08	Week 16	N/A	N/A	N/A	19.9	7.0	31.5	16.9	2.7	28.8
08-Feb-08	Week 17	N/A	N/A	N/A	17.8	4.2	27.1	19.8	7.8	29.5
15-Feb-08	Week 18	N/A	N/A	N/A	18.6	7.0	31.1	17.0	3.7	29.1
22-Feb-08	Week 19	N/A	N/A	N/A	20.4	5.4	31.1	19.7	6.7	29.0
29-Feb-08	Week 20	N/A	N/A	N/A	18.7	3.7	30.7	16.3	1.6	28.2
07-Mar-08	Week 21	N/A	N/A	N/A	18.3	4.2	31.1	18.4	3.7	29.7
14-Mar-08	Week 22	N/A	N/A	N/A	21.8	9.0	34.0	19.6	8.4	30.2
21-Mar-08	Week 23	N/A	N/A	N/A	18.0	3.3	31.5	20.7	10.6	29.6
28-Mar-08	Week 24	N/A	N/A	N/A	23.1	12.9	36.1	20.7	10.6	29.6

Table 3-2. Effects of production systems and strawberry cultivars on chlorophyll content and plant canopy diameter at 8 and 12 weeks after transplanting (WAT). 2007-08 Season.

	Diameter		Chlorophyll content	
	cm		SPAD value	
Production Systems	8 WAT	12 WAT	8 WAT	12 WAT
Tunnel	26 a[Z]	33 a	43.7	41.2 b
Open-field	22 b	28 b	44.4	44.4 a
P value	*0.0032*	*0.0079*	*0.4127*	*0.0048*
Cultivars				
‘Strawberry Festival’	28 a	34 a	43.0 b	41.3 b
‘Winter Dawn’	23 b	30 b	44.0 b	43.3 a
‘Florida Elyana’	20 c	26 c	45.2 a	43.7 a
P value	*<0.0001*	*<0.0001*	*0.0029*	*0.0004*

[Z]Values followed by the different letters represent significant differences among treatments.

Table 3-3. Effects of production systems and strawberry cultivars on early yield and total yield. 2007-08 Season.

	Early yield	Total yield
Production Systems	----------t/ha----------	
Tunnel	2.0 a[Z]	12.2 a
Open-field	1.3 b	7.5 b
P value	<0.0001	<0.0001
Cultivars		
‘Strawberry Festival’	2.4 a	12.4 a
‘Winter Dawn’	1.6 b	9.4 b
‘Florida Elyana’	1.0 c	7.7 c
P value	<0.0001	<0.0001

[Z]Values followed by the different letters represent significant differences among treatments.

Table 3-4. Effects of production systems and strawberry cultivars on yield 6 harvests following a freeze or near freeze temperature event on January 3 when temperature dropped to -2.6 ^{o}C. 2007-08 Season.

	Yield after freeze
Production Systems	(t/ha)
Tunnel	1.4 a[z]
Open-field	0.8 b
P value	0.0001
Cultivars	
‘Strawberry Festival’	1.5 a
‘Winter Dawn’	1.3 b
‘Florida Elyana’	0.7 c
P value	<0.0001

[z]Values followed by the different letters represent significant differences among treatments.

Table 3-5. Data from temperature sensors located in open-field and high tunnel at 10 cm height, and temperature from FAWN weather report, for Balm during 2008-09 season.

Date	Week	Tunnel			Open-Field			Fawn		
		Temperature (^{O}C)								
		Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
20-Oct-08	Week 1	21.7	14.1	27.9	21.8	13.7	28.3	22.2	12.9	29.1
27-Oct-08	Week 2	16.2	4.2	27.1	16.2	3.7	27.5	15.9	1.6	27.4
3-Nov-08	Week 3	19.2	11.0	28.7	19.1	10.6	29.1	18.8	9.9	28.9
10-Nov-08	Week 4	20.2	7.4	32.3	20.8	7.4	32.8	20.4	3.1	32.0
17-Nov-08	Week 5	12.8	2.9	24.8	12.8	2.9	24.0	12.0	0.8	23.6
24-Nov-08	Week 6	15.7	5.0	28.3	15.5	4.6	28.3	14.7	0.6	27.2
1-Dec-08	Week 7	15.4	3.3	26.0	15.3	2.9	26.7	14.7	1.3	26.3
8-Dec-08	Week 8	17.2	5.0	30.3	17.1	4.6	30.3	16.9	3.0	29.2
15-Dec-08	Week 9	20.0	11.8	31.1	19.4	11.4	28.3	18.9	9.5	27.4
22-Dec-08	Week 10	19.9	6.6	31.5	19.4	6.6	30.3	19.0	6.1	28.5
29-Dec-08	Week 11	18.8	8.2	31.5	17.9	7.8	28.3	17.5	5.3	27.3
5-Jan-09	Week 12	18.5	7.0	34.4	17.4	6.2	30.3	16.8	4.0	29.0
12-Jan-09	Week 13	13.5	2.9	31.9	12.4	2.5	26.0	12.0	1.6	25.7
19-Jan-09	Week 14	14.0	1.2	31.1	11.3	-0.2	28.7	10.7	-4.7	26.1
26-Jan-09	Week 15	18.7	3.7	32.8	16.6	2.5	29.1	16.4	1.4	28.4
2-Feb-09	Week 16	13.7	-1.1	29.1	11.0	-1.1	26.0	10.7	-2.7	24.2
9-Feb-09	Week 17	20.9	8.2	37.0	19.0	6.6	31.1	18.6	5.4	29.5
16-Feb-09	Week 18	17.4	3.3	32.3	15.9	2.9	26.3	15.4	-0.2	24.8
23-Feb-09	Week 19	18.8	6.2	36.6	17.1	5.4	30.3	16.4	4.9	28.4
2-Mar-09	Week 20	17.6	2.9	38.8	15.5	2.0	31.9	14.5	1.0	28.3
9-Mar-09	Week 21	24.2	12.9	41.1	21.8	11.8	33.6	20.6	9.7	31.2
16-Mar-09	Week 22	21.9	11.4	39.7	21.1	11.0	31.9	20.3	11.0	29.8
23-Mar-09	Week 23	21.7	11.0	35.3	21.3	11.0	33.6	20.7	10.6	31.4
30-Mar-09	Week 24	23.9	9.0	37.0	23.4	8.6	34.0	20.8	7.4	31.3

Table 3-6. Effects of production systems and strawberry cultivars on chlorophyll content and plant canopy diameter at 8 and 12 weeks after transplanting (WAT). 2008-09 Season.

	Diameter		Chlorophyll Content	
	Cm		SPAD Value	
Production Systems	8 WAT	12 WAT	8 WAT	12 WAT
Tunnel	24	31 a	46.3	49.1 a
Open field	23	28 b	48.4	48.0 b
P value	*0.1527*	*0.0018*	*0.0741*	*0.0174*
Cultivars				
‘Strawberry Festival’	26 a	35 a	45.2 b	46.4 c
‘Winter Dawn’	23 b	27 b	48.5 a	48.7 b
‘Florida Elyana’	22 b	27 c	48.5 a	50.6 a
P value	*0.0002*	*<0.0001*	*0.0029*	*0.0004*

Table 3-7. Effects of production systems and strawberry cultivars on early yield and total yield. 2008-09 Season.

Production Systems	Early yield	Total yield
	(t/ha)	
Tunnel	2.9 a	14.4 a
Open field	2.5 b	9.6 b
P value	*0.0231*	*0.0030*
Cultivars		
‘Strawberry Festival’	3.3 a	18.6 a
‘Winter Dawn’	2.7 b	9.0 b
‘Florida Elyana’	2.0 c	8.4 b
P value	*<0.0001*	*<0.0001*

Table 3-8. Effects of production systems and strawberry cultivars on yield 6 harvests following a freeze or near freeze temperature event. 2008-09 Season.

	Date	January 21 to 23	February 5	February 21
	Minimum Temp. (^{O}C)	-3, -5.6 , -5	-2.8	-0.6
Production Systems	Cultivars	----------t/ha----------		
Tunnel	‘Strawberry Festival’	4.6 a	4.4 a	5.4 a
Tunnel	‘Winter Dawn’	3.0 bc	3.0 b	2.7 c
Tunnel	‘Florida Elyana’	2.4 c	2.6 b	2.7 cd
Open-Field	‘Strawberry Festival’	3.3 b	3.1 b	3.7 b
Open-Field	‘Winter Dawn’	0.8 d	0.9 c	1.1 e
Open-Field	‘Florida Elyana’	1.3 d	1.2 c	1.7 de
P Value		*0.0184*	*0.0267*	*0.0135*

Figure 3-1. Overview of strawberry field production in open field (top) and in high tunnel (bottom) on a freeze event. January 3, 2008, temperature dropped to -2.8^{o}C.

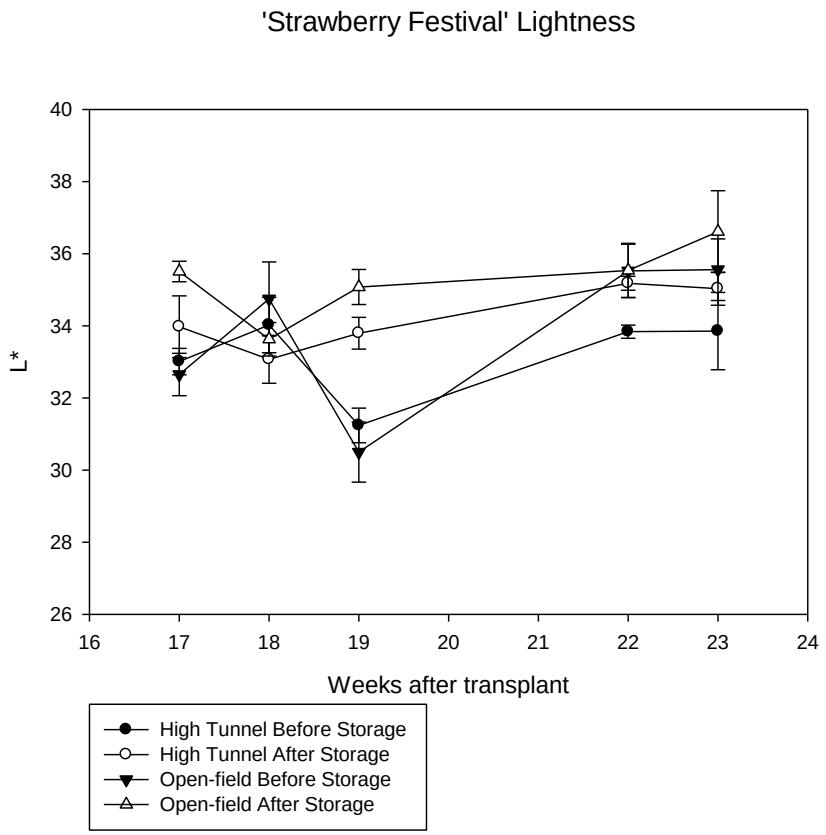

Figure 3-2. Effects of production system on strawberry skin color lightness on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

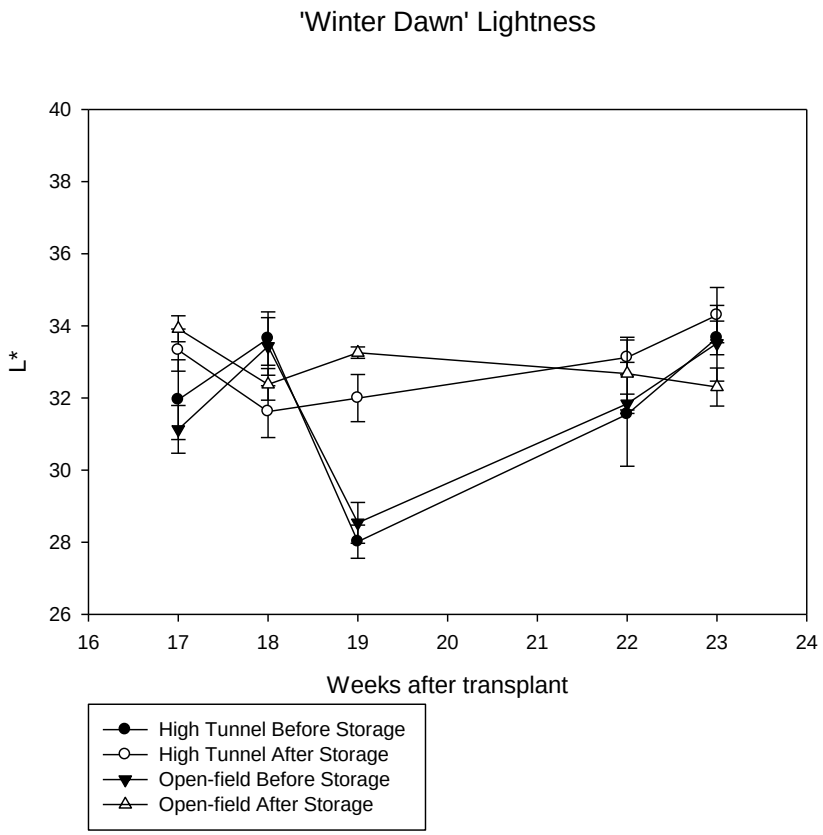

Figure 3-3. Effects of production system on strawberry skin color lightness on 'Winter Dawn' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

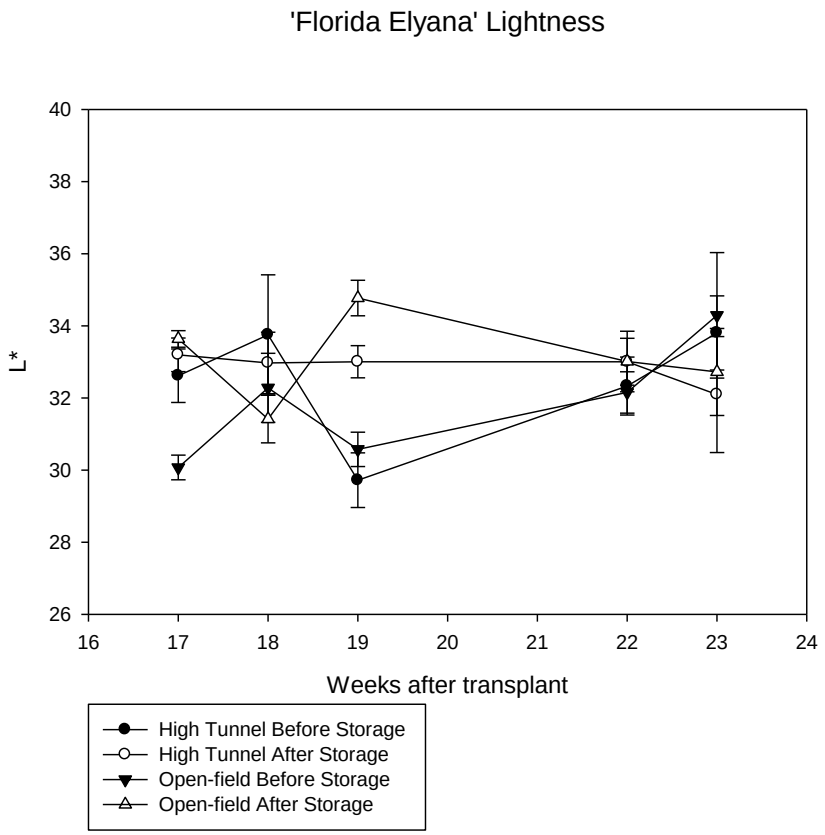

Figure 3-4. Effects of production system on strawberry skin color lightness on 'Florida Elyana' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

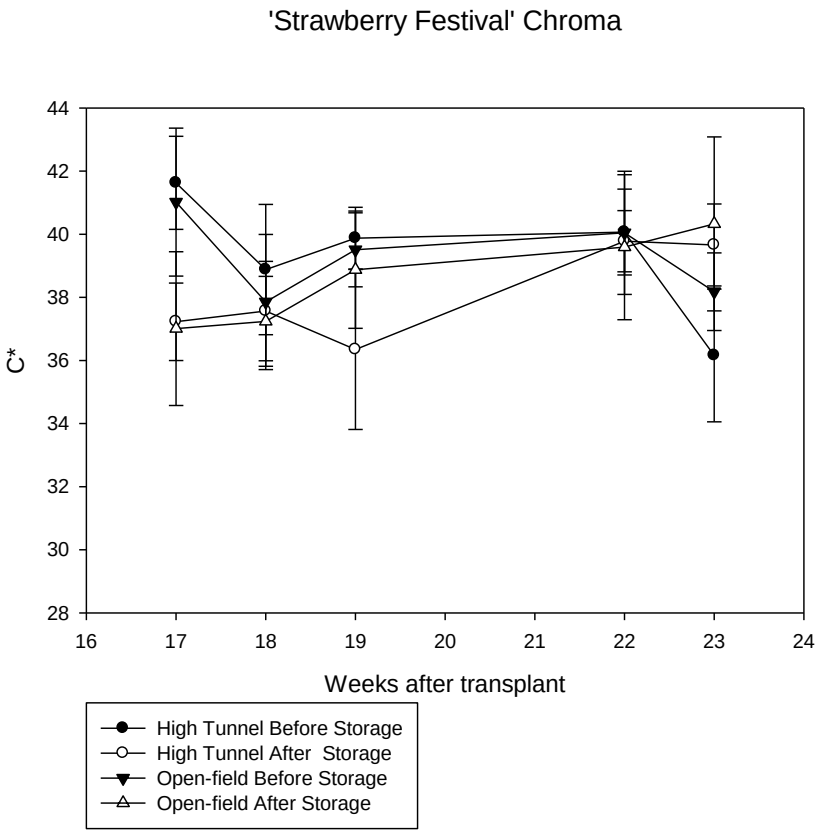

Figure 3-5. Effects of production system on strawberry skin color chroma on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

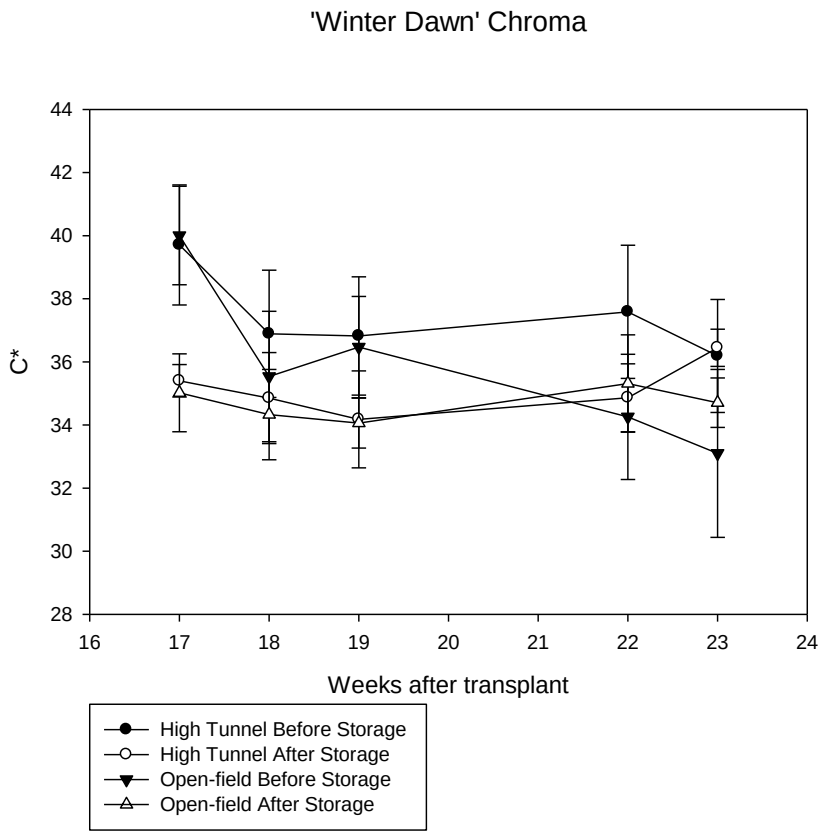

Figure 3-6. Effects of production system on strawberry skin color chroma on 'Winter Dawn' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

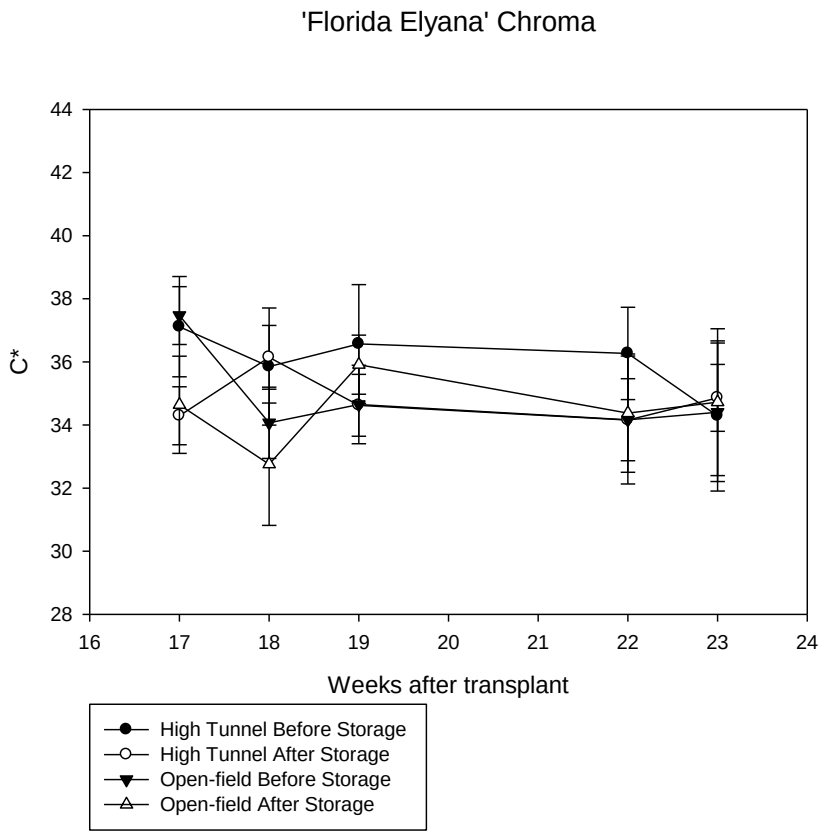

Figure 3-7. Effects of production system on strawberry skin color chroma on 'Florida Elyana' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

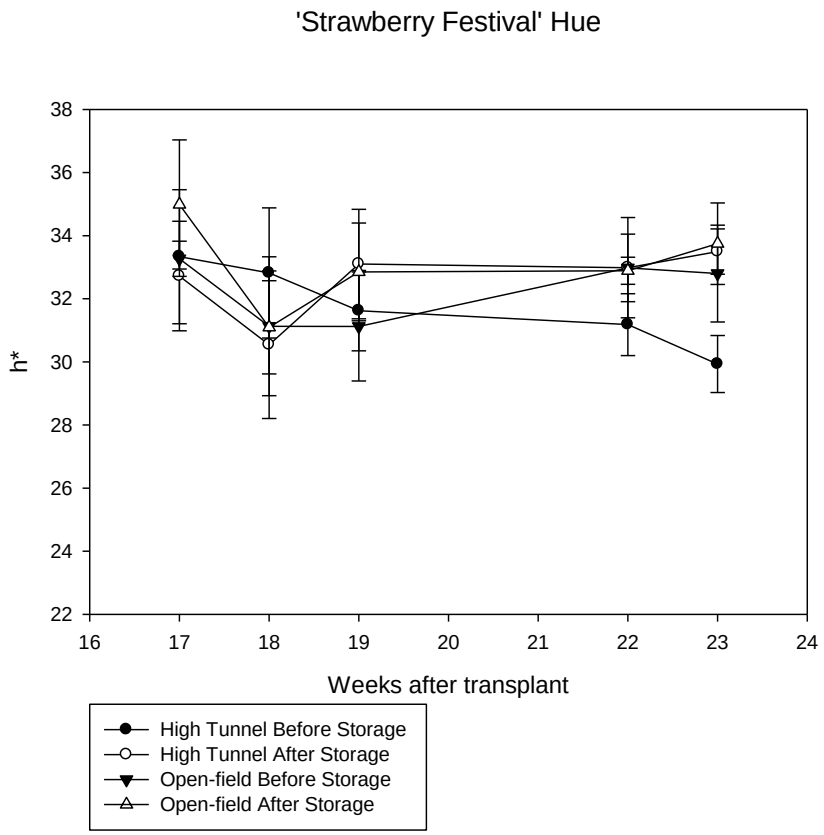

Figure 3-8. Effects of production system on strawberry skin color hue angle on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

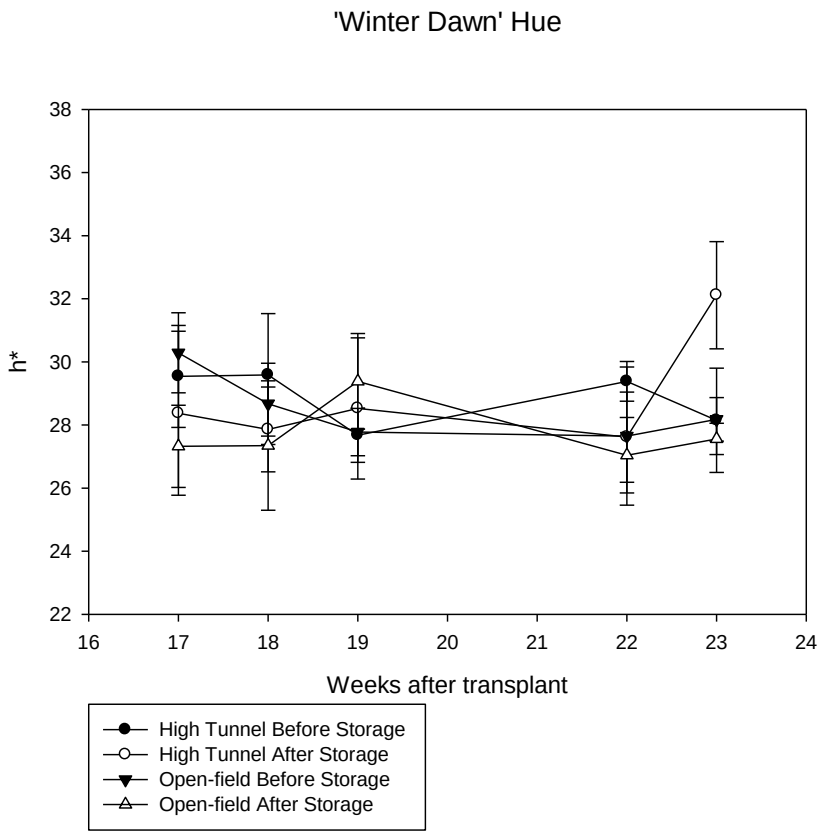

Figure 3-9. Effects of production system on strawberry skin color hue angle on 'Winter Dawn' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

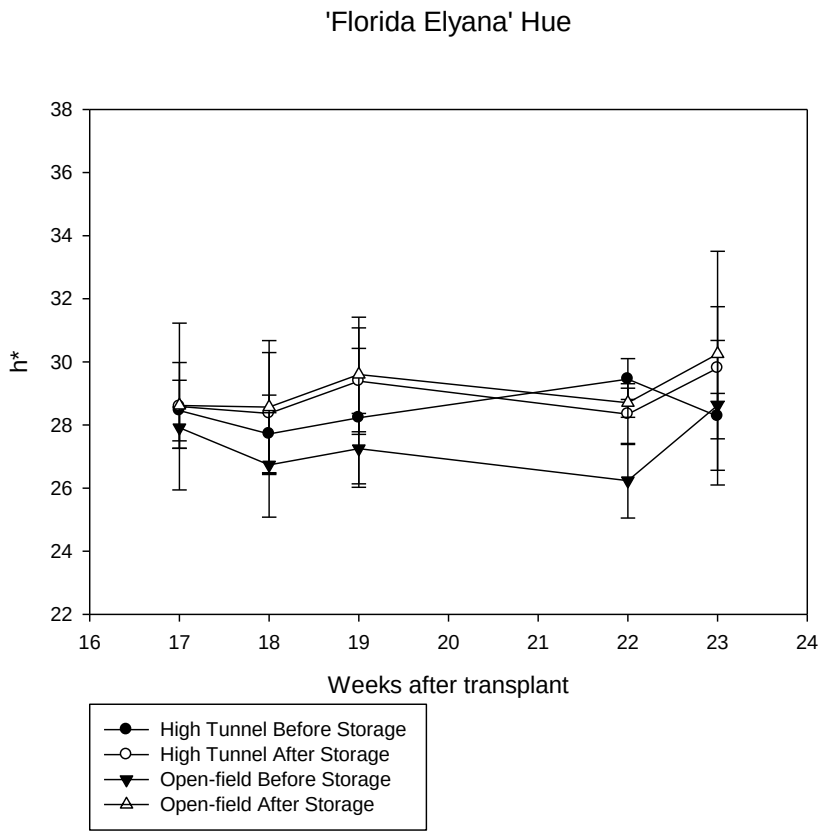

Figure 3-10. Effects of production system on strawberry skin color hue angle on 'Florida Elyana' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2007-08 Season.

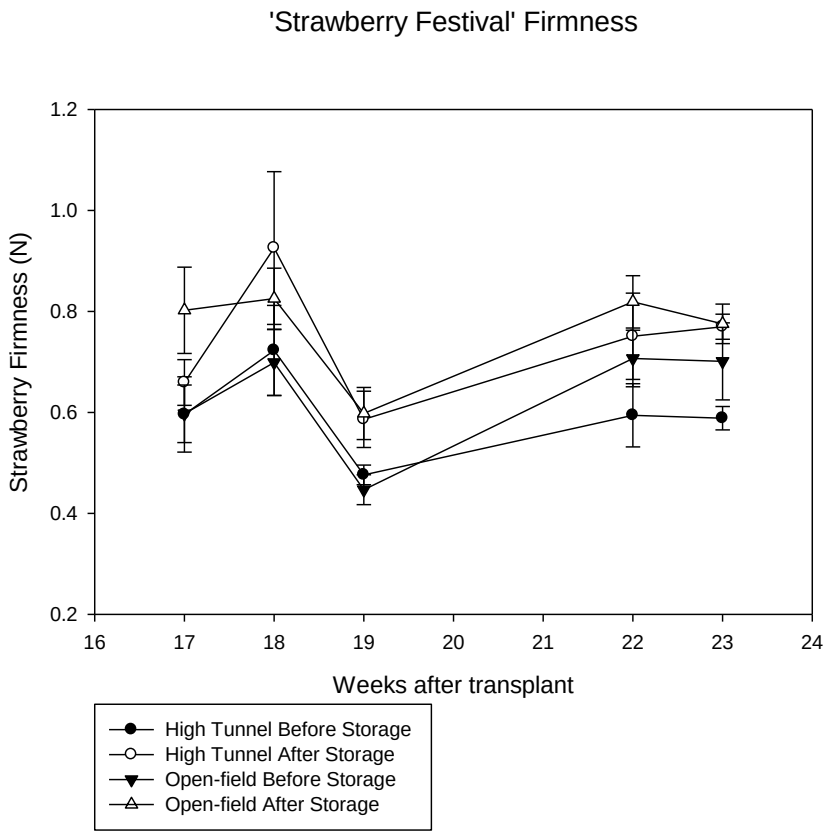

Figure 3-11. Effects of production system on strawberry firmness on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2007-08 Season.

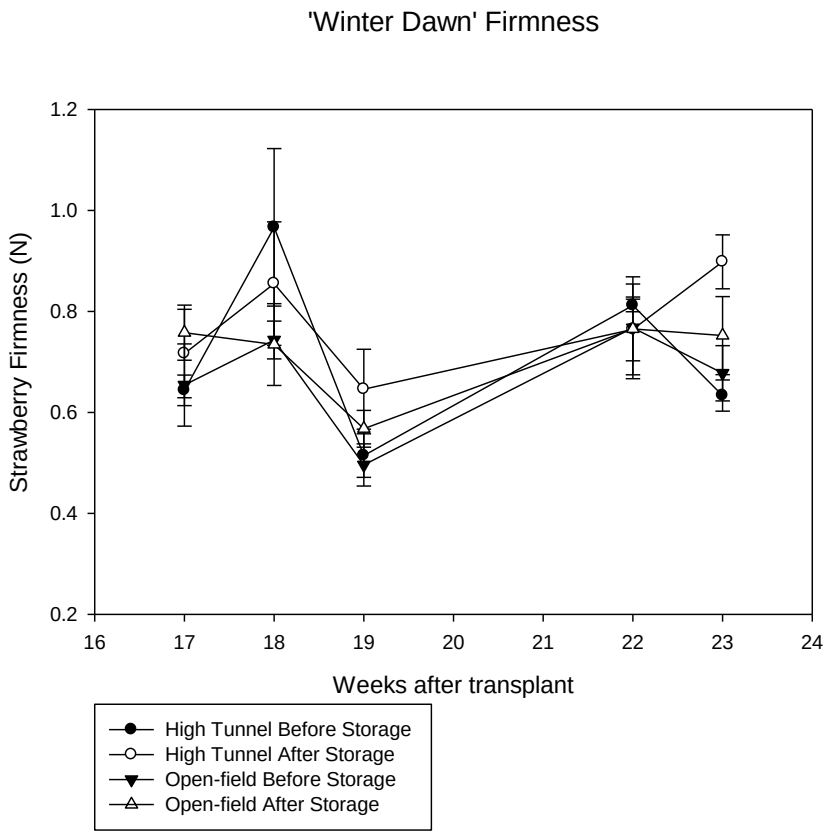

Figure 3-12. Effects of production system on strawberry firmness on 'Winter Dawn' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

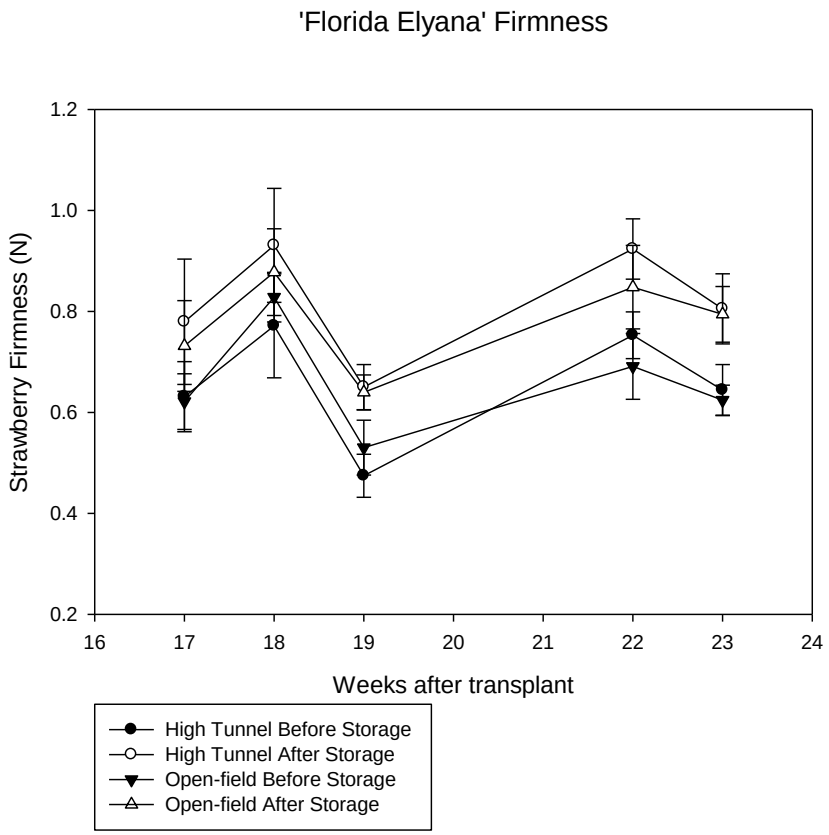

Figure 3-13. Effects of production system on strawberry firmness on 'Florida Elyana' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

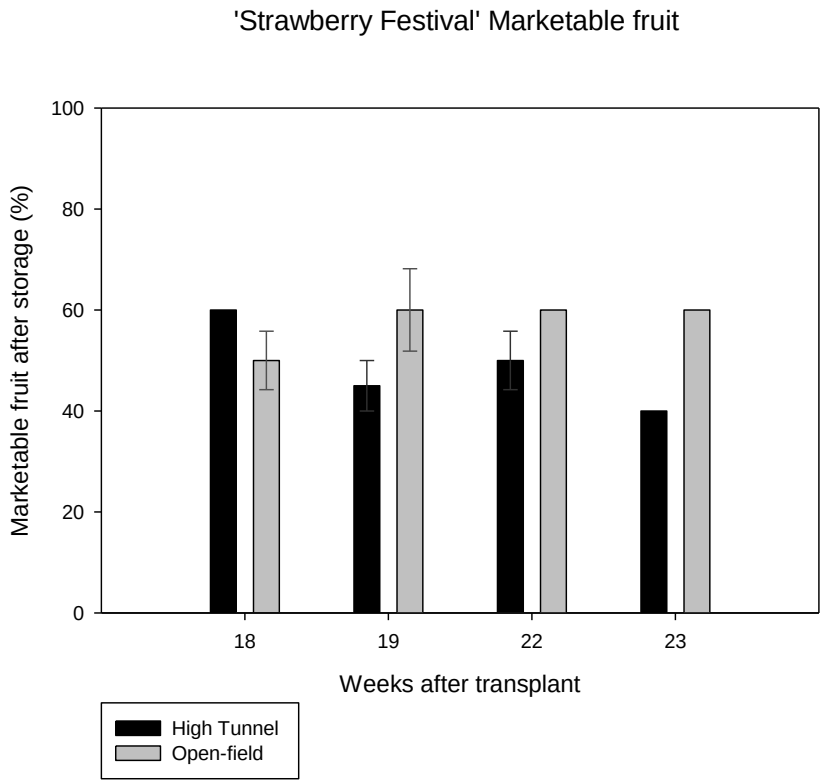

Figure 3-14. Effects of production system on marketable fruit on 'Strawberry Festival' strawberry after 8 days storage at 7.2^{o}C in five different storage tests. 2007-08 Season.

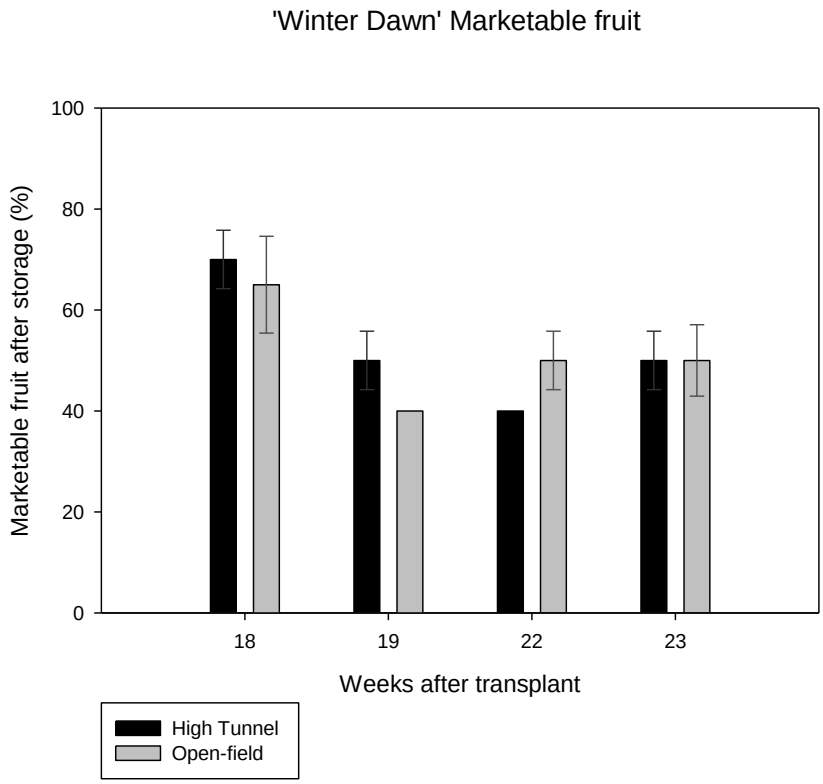

Figure 3-15. Effects of production system on marketable fruit on ‘Winter Dawn’ strawberry after 8 days storage at 7.2^{o}C in five different storage tests. 2007-08 Season.

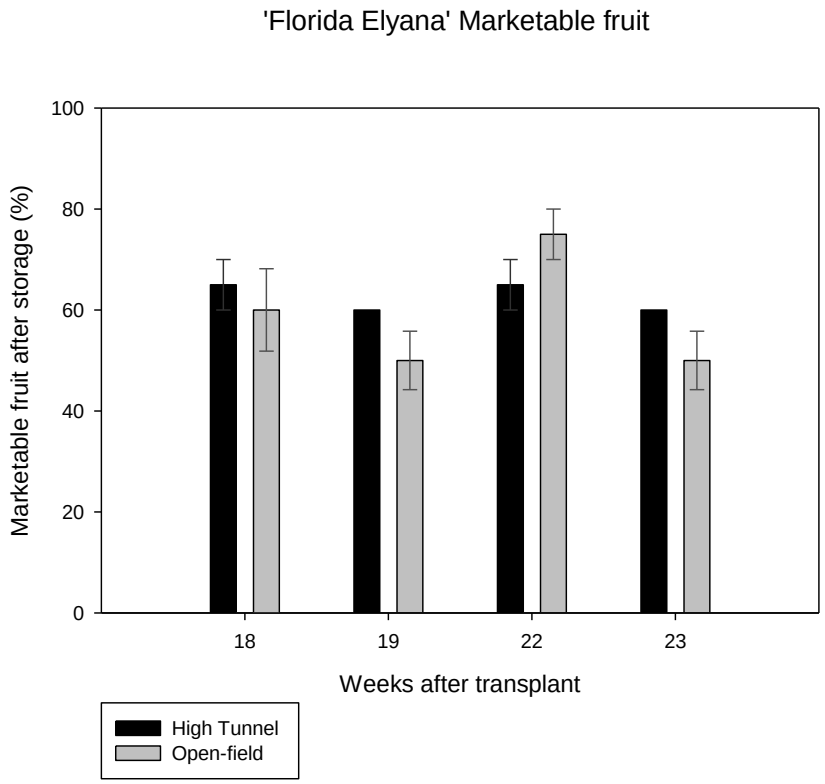

Figure 3-16. Effects of production system on marketable fruit on 'Florida Elyana' strawberry after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

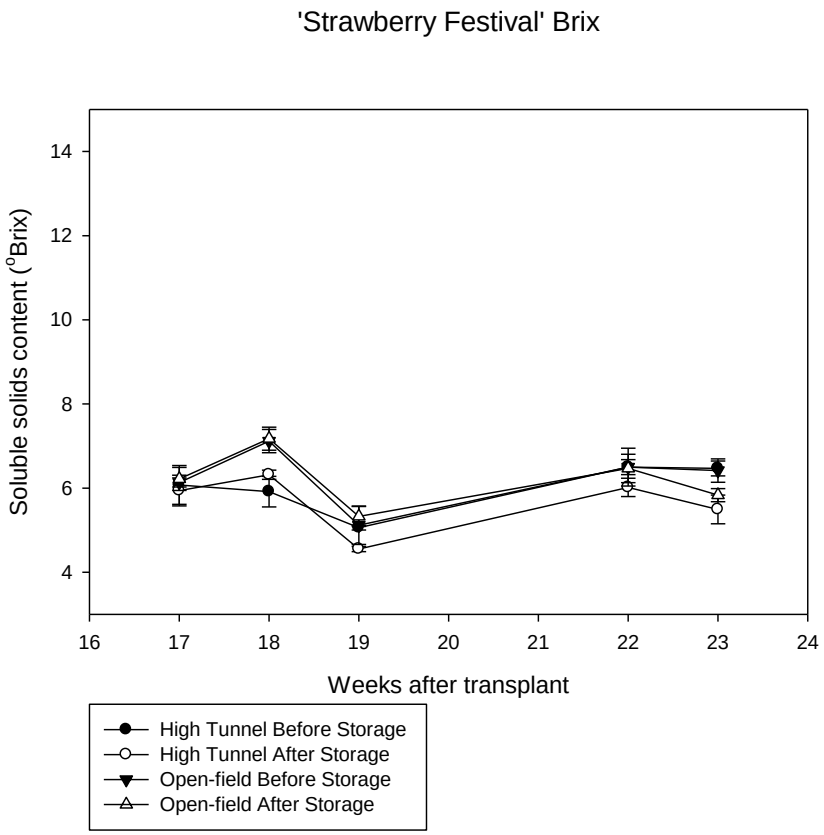

Figure 3-17. Effects of production system on strawberry soluble solids content on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08. Season.

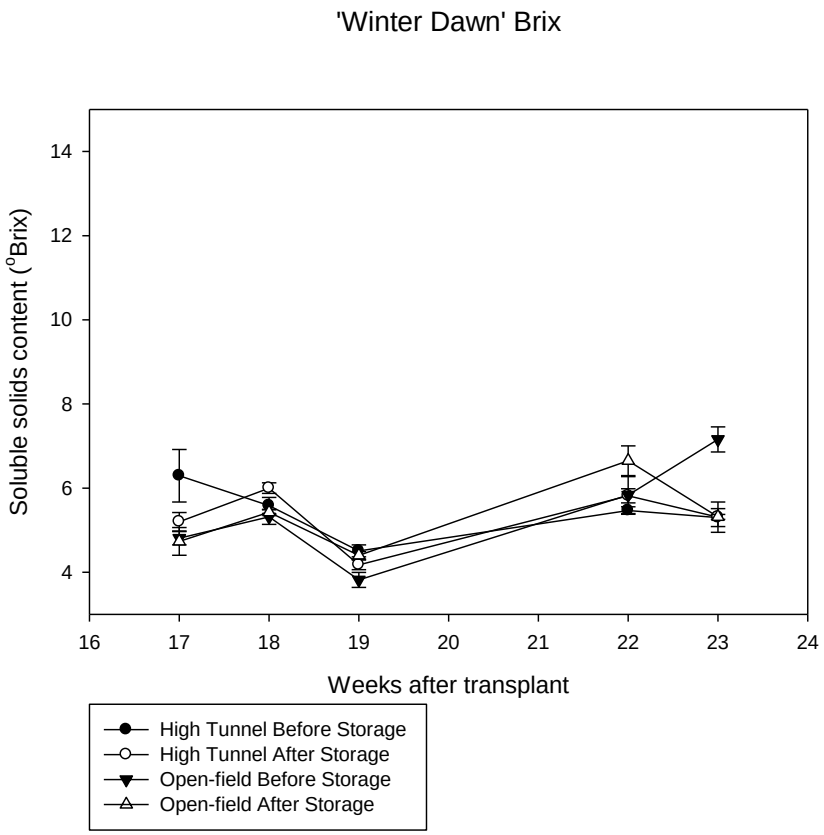

Figure 3-18. Effects of production system on strawberry soluble solids content on 'Winter Dawn' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

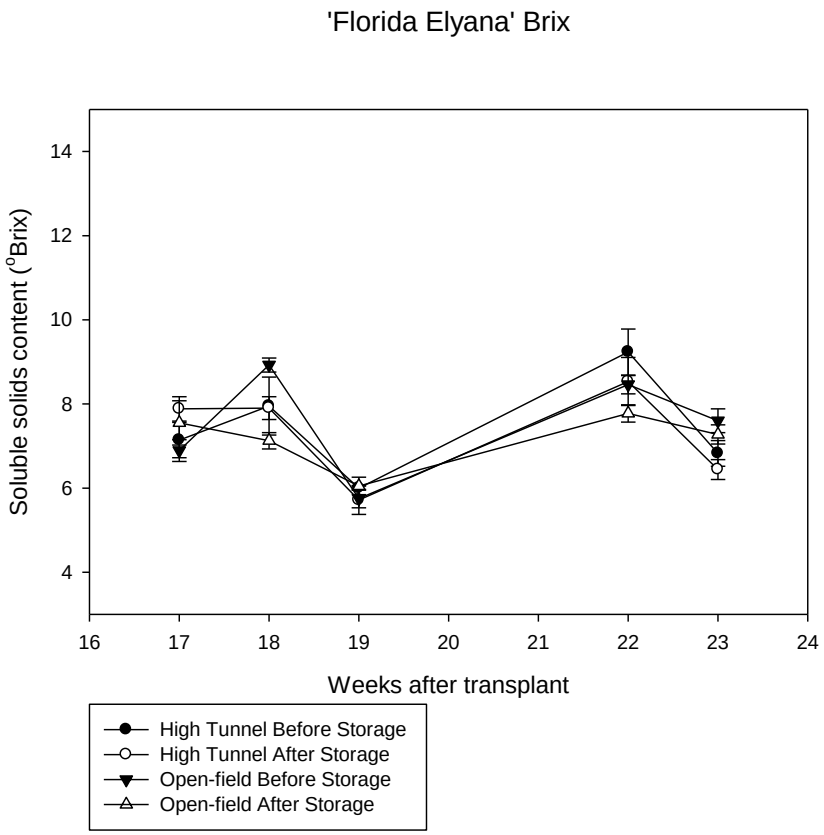

Figure 3-19. Effects of production system on strawberry soluble solids content on 'Florida Elyana' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

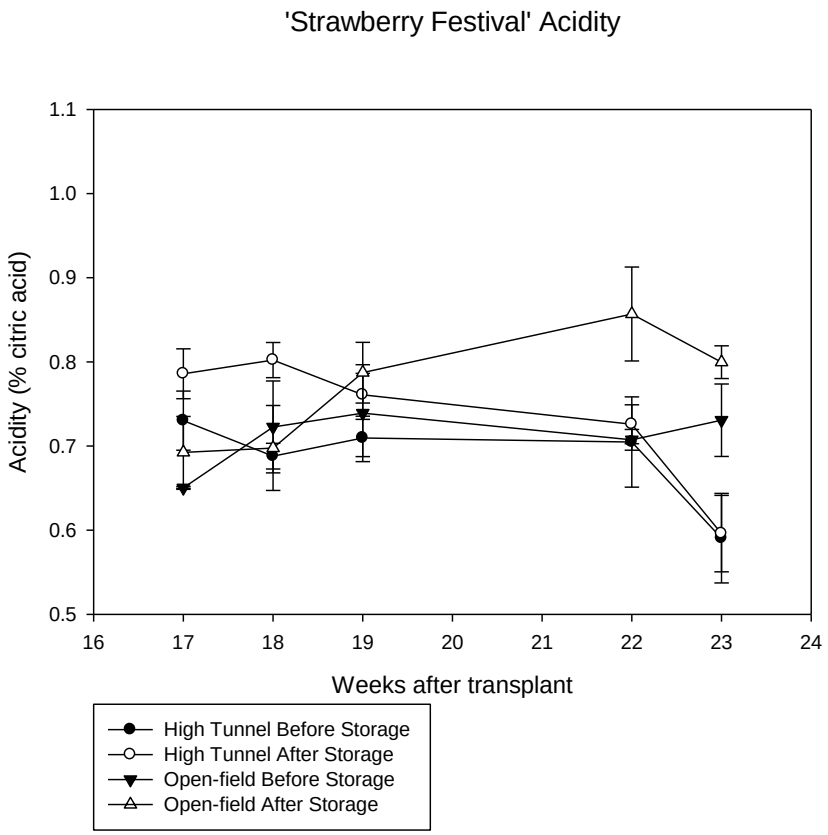

Figure 3-20. Effects of production system on strawberry total titratable acidity on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

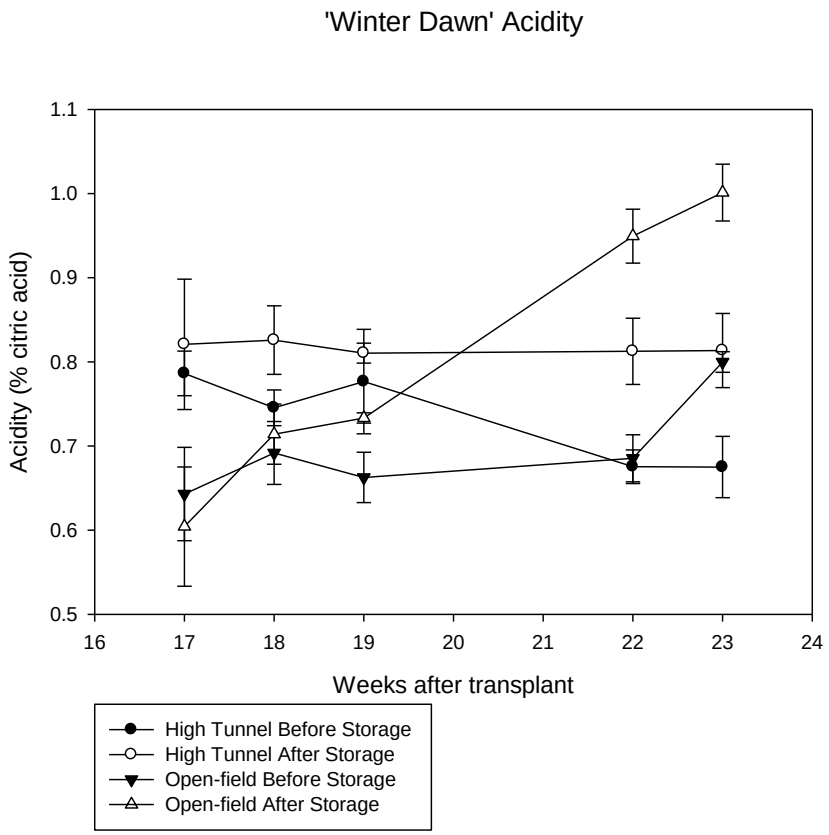

Figure 3-21. Effects of production system on strawberry total titratable acidity on 'Winter Dawn' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2007-08 Season.

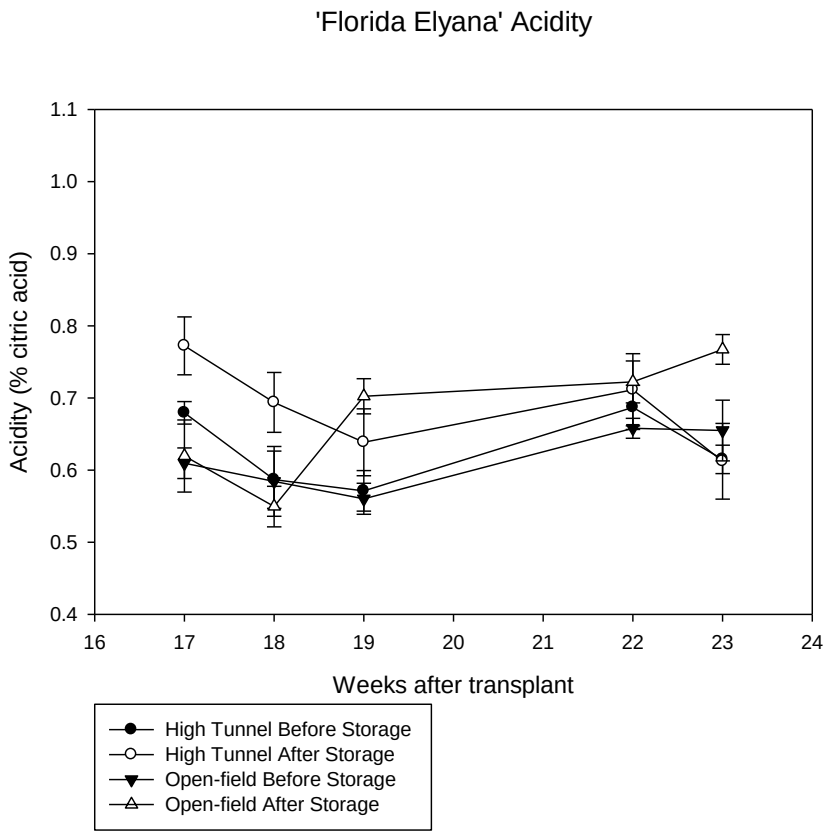

Figure 3-22. Effects of production system on strawberry total titratable acidity on 'Florida Elyana' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

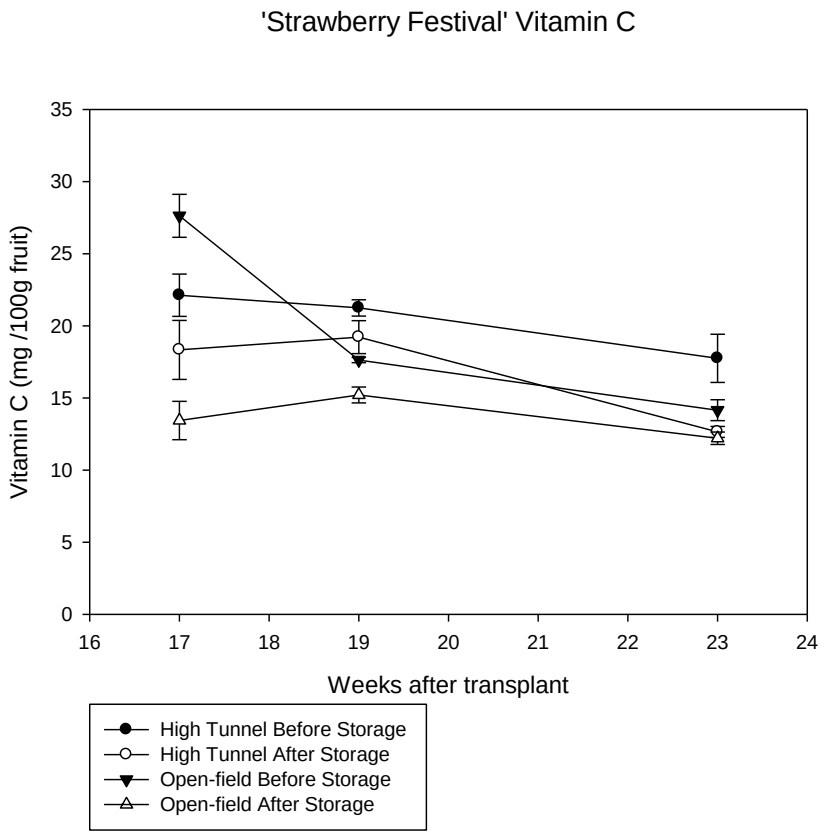

Figure 3-23. Effects of production system on strawberry vitamin C content on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

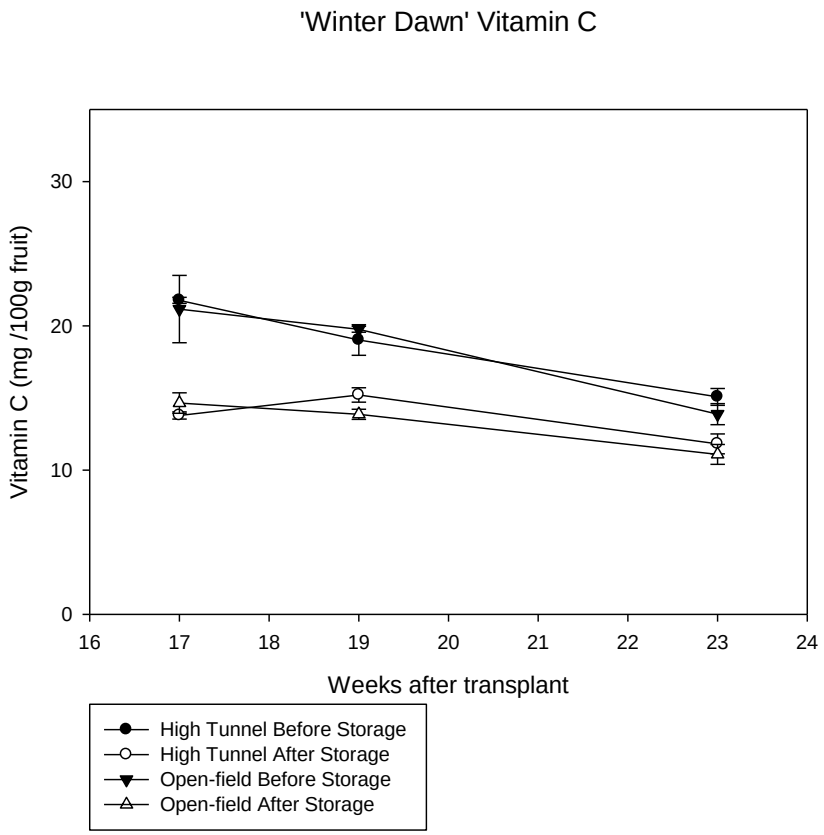

Figure 3-24. Effects of production system on strawberry vitamin C content on 'Winter Dawn' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2007-08 Season.

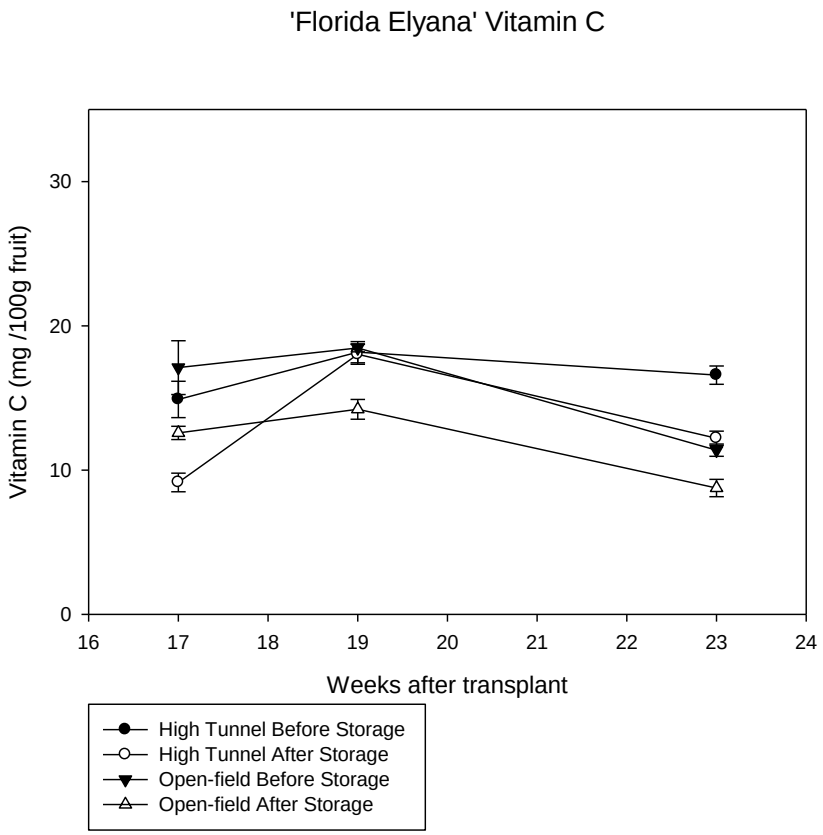

Figure 3-25. Effects of production system on strawberry vitamin C on 'Florida Elyana' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2007-08 Season.

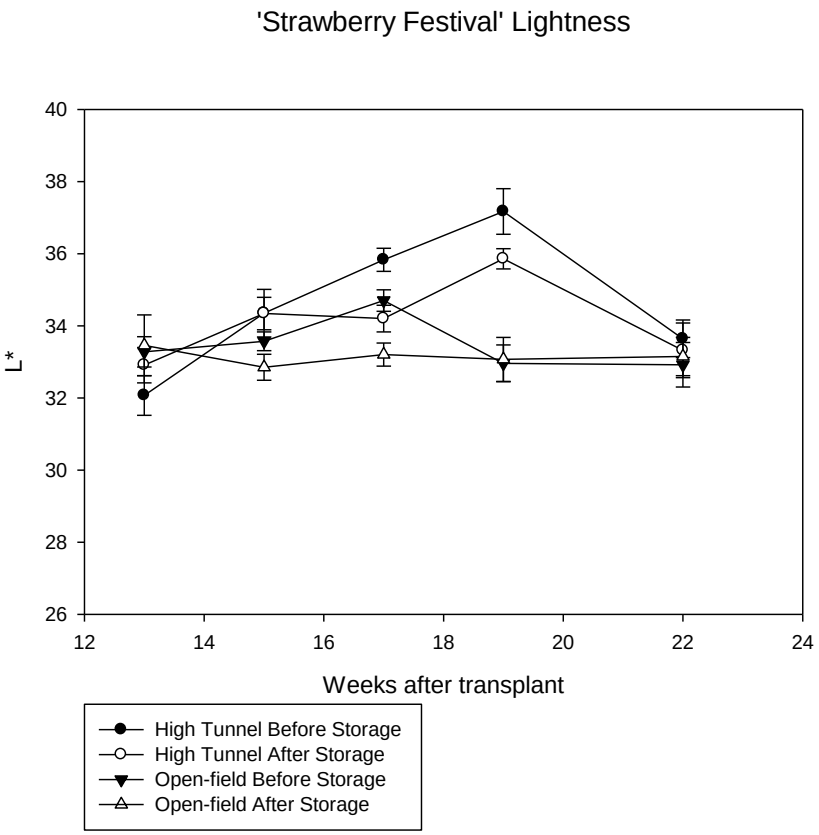

Figure 3-26. Effects of production system on strawberry skin color lightness on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2008-09 Season.

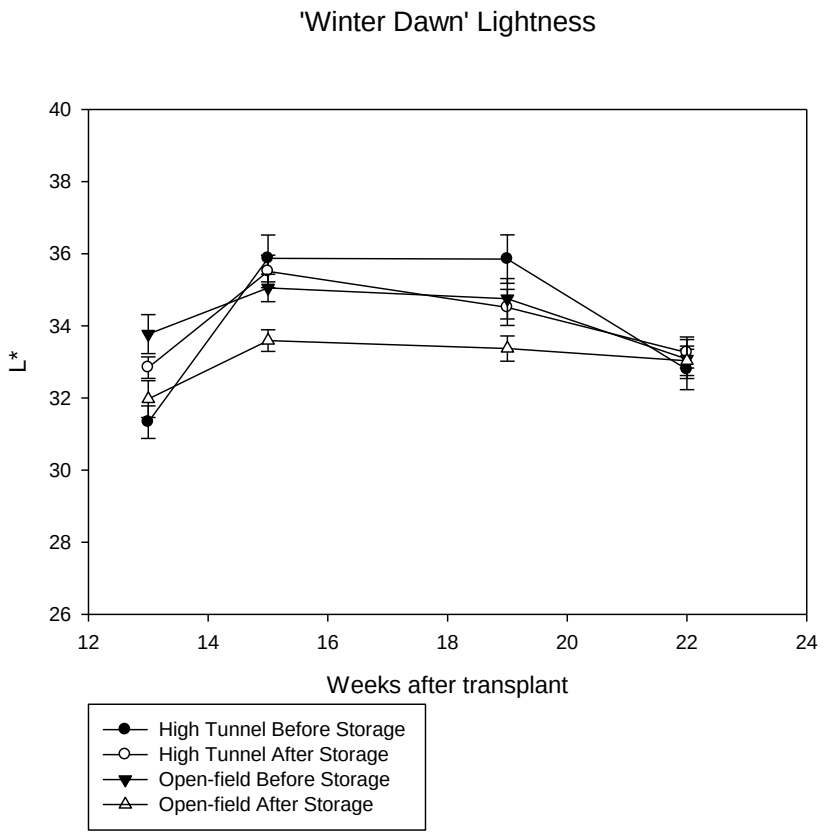

Figure 3-27. Effects of production system on strawberry skin color lightness on 'Winter Dawn' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2008-09 Season.

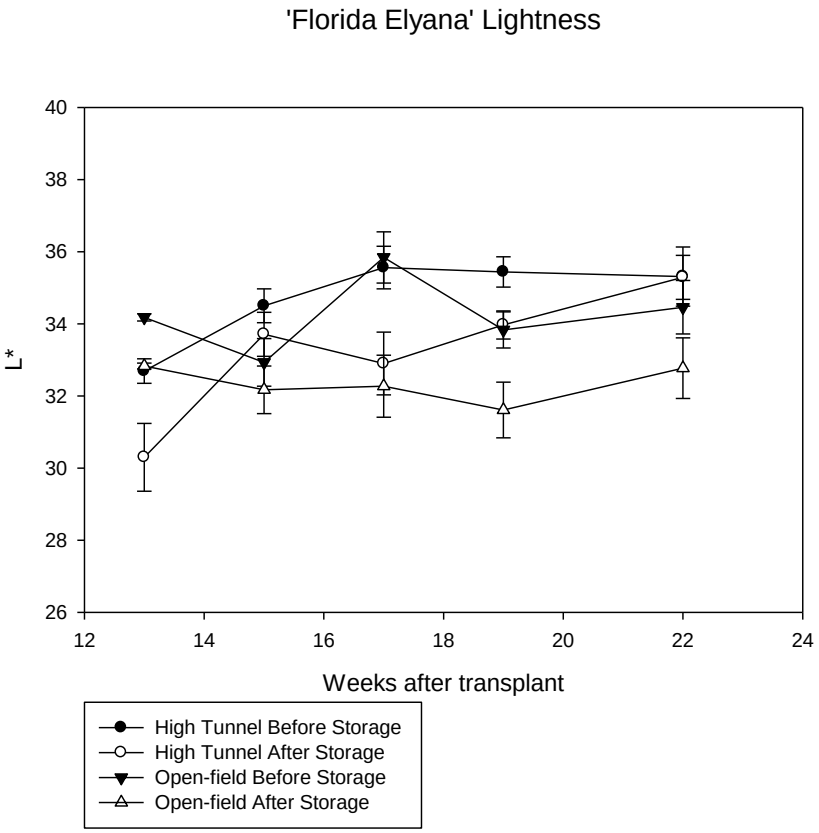

Figure 3-28. Effects of production system on strawberry skin color lightness on 'Florida Elyana' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2008-09 Season.

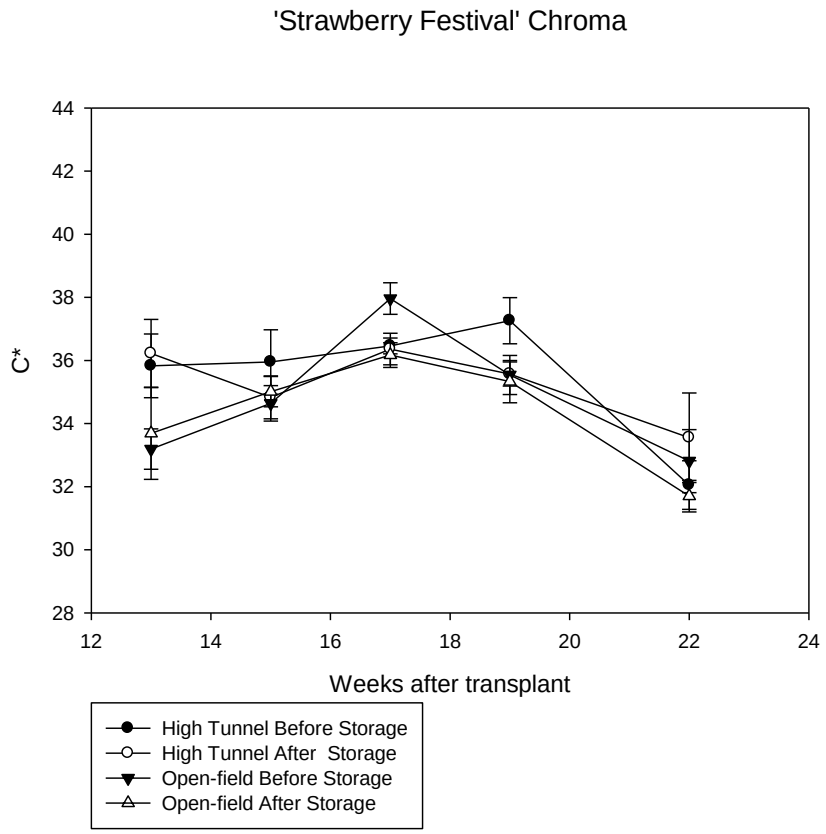

Figure 3-29. Effects of production system on strawberry skin color chroma on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2008-09 Season.

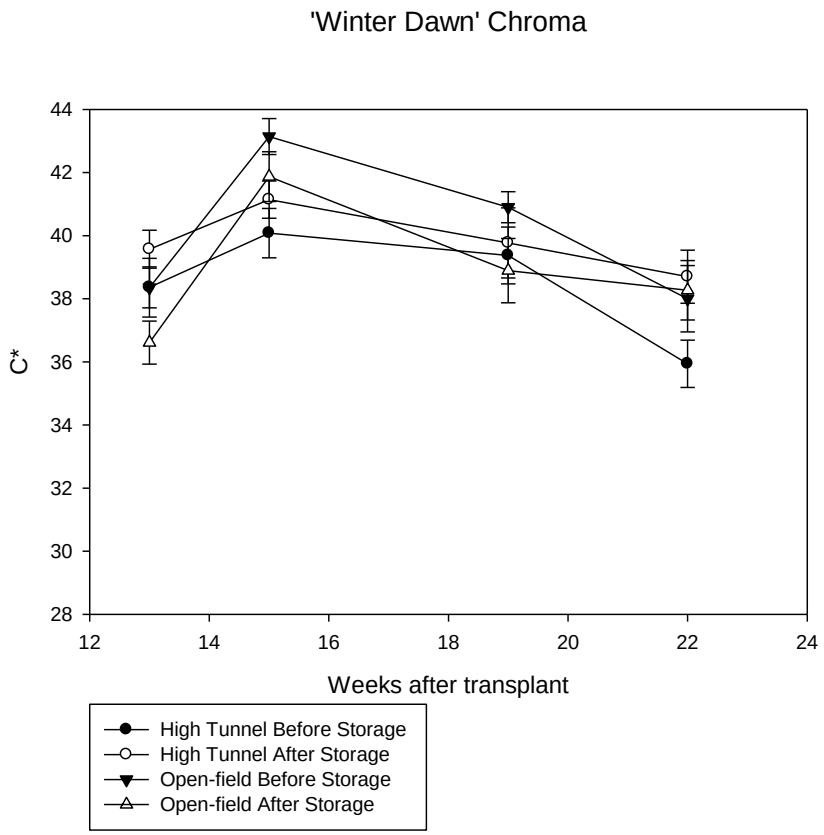

Figure 3-30. Effects of production system on strawberry skin color chroma on 'Winter Dawn' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2008-09 Season.

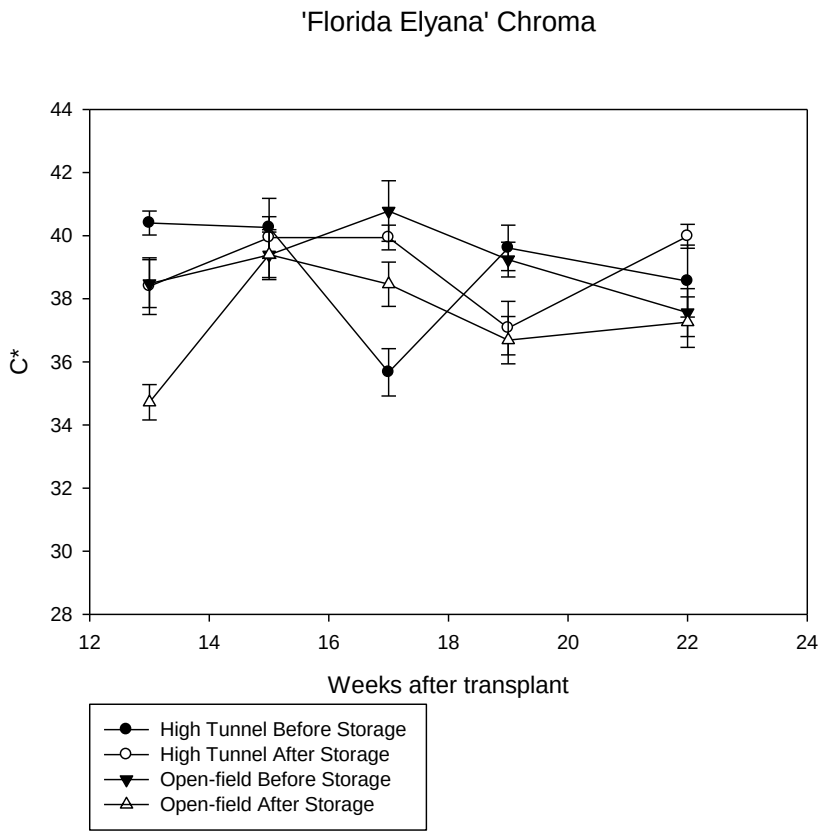

Figure 3-31. Effects of production system on strawberry skin color chroma on 'Florida Elyana' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2008-09 Season.

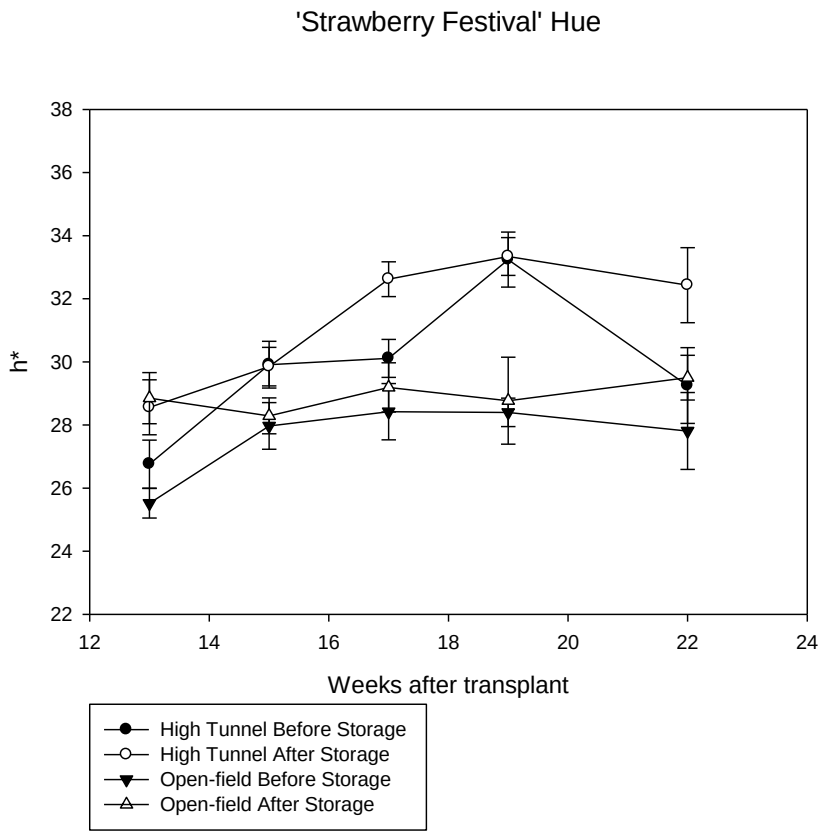

Figure 3-32. Effects of production system on strawberry skin color hue angle on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2008-09 Season.

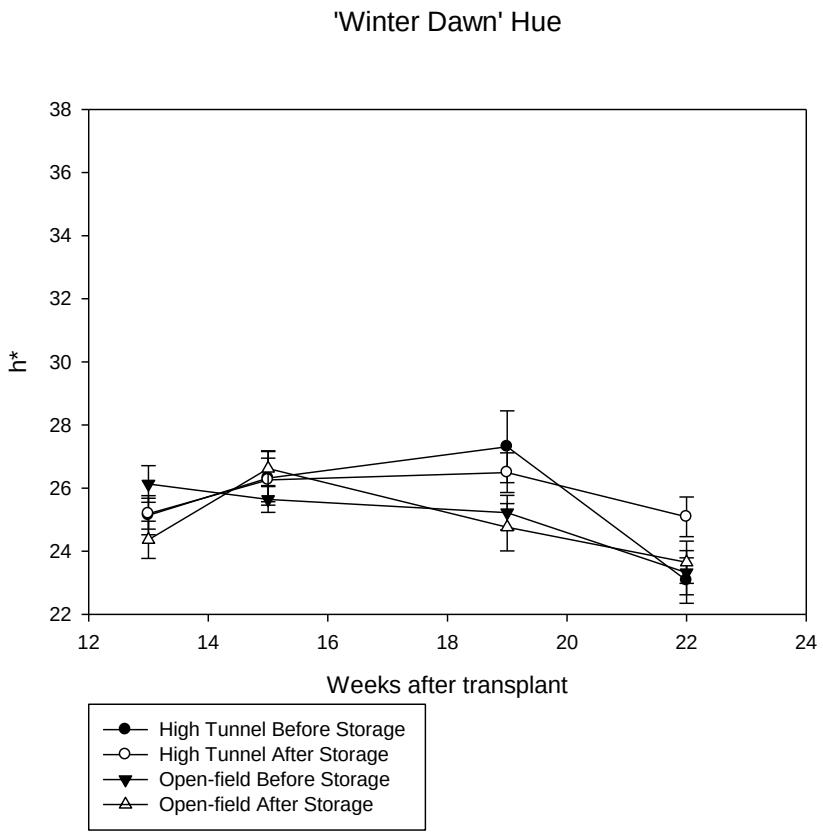

Figure 3-33. Effects of production system on strawberry skin color hue angle on 'Winter Dawn' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2008-09 Season.

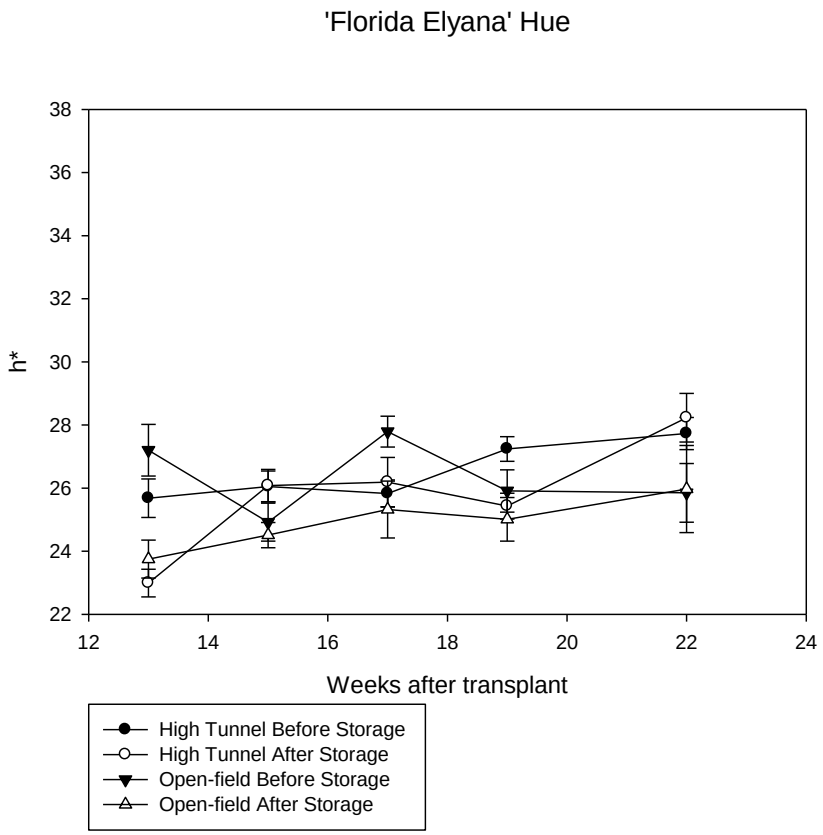

Figure 3-34. Effects of production system on strawberry skin color hue angle on 'Florida Elyana' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2008-09 Season.

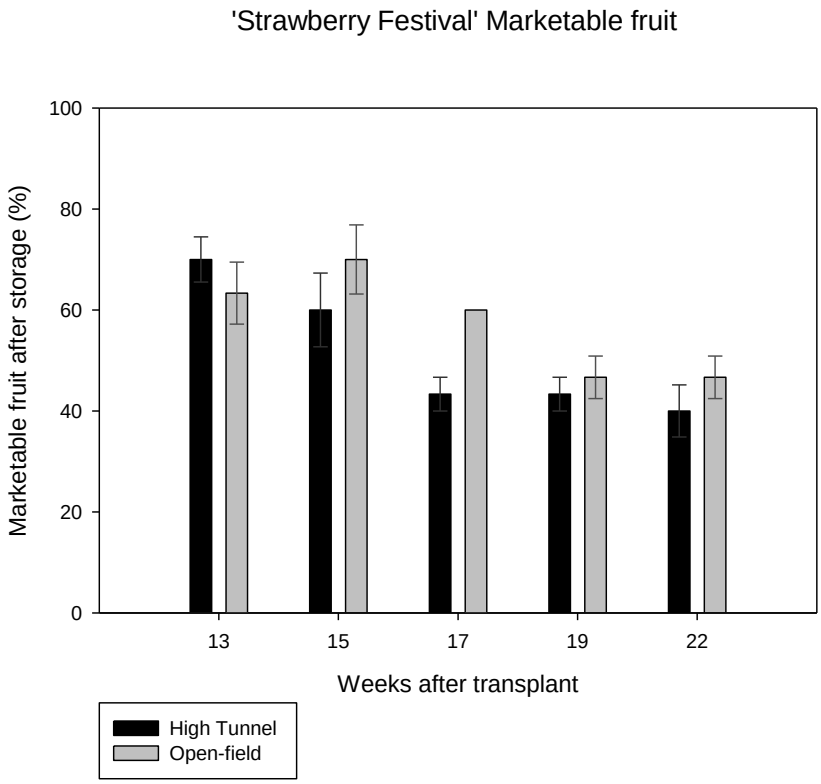

Figure 3-35. Effects of production systems on 'Strawberry Festival' marketable fruit after 8 days storage at 7.2°C in five different storage tests. 2008-09 Season.

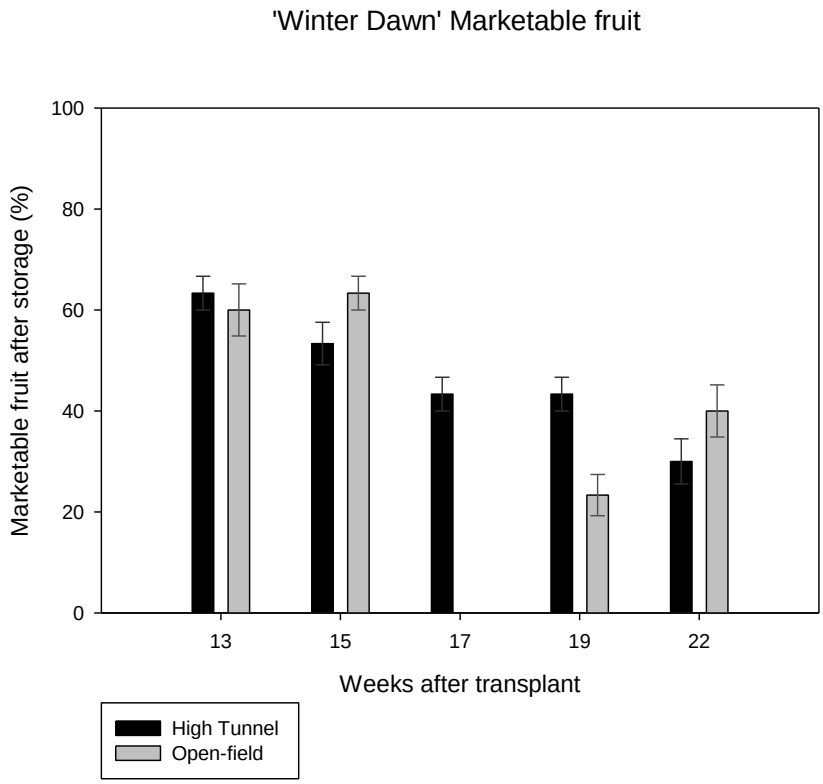

Figure 3-36. Effects of production systems on ‘Winter Dawn’ marketable fruit after 8 days storage at 7.2^{o}C in five different storage tests. 2008-09 Season.

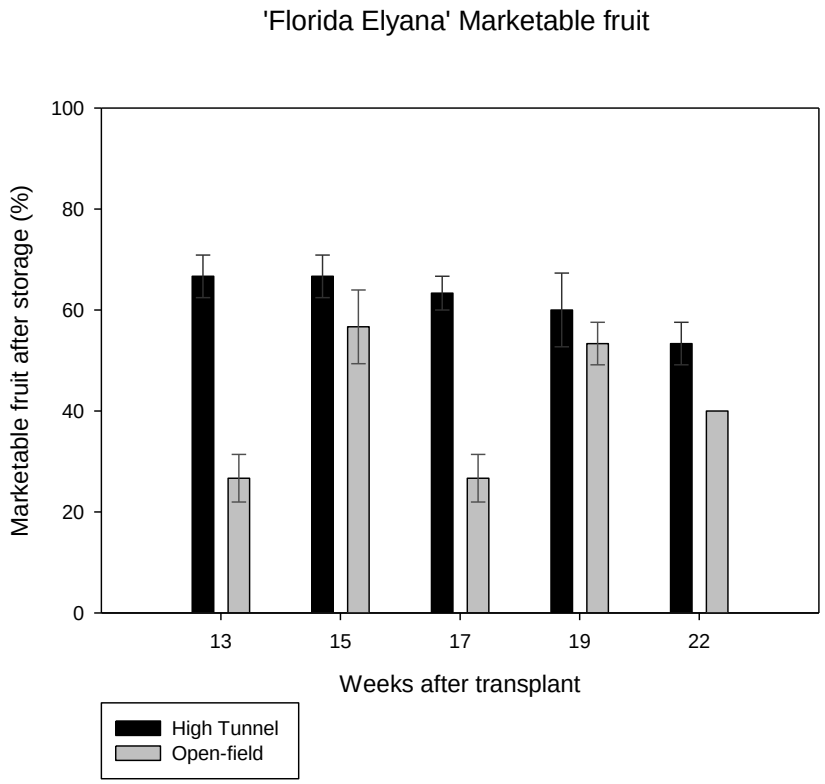

Figure 3-37. Effects of production systems on ‘Florida Elyana’ marketable fruit after 8 days storage at 7.2^{o}C in five different storage tests. 2008-09 Season.

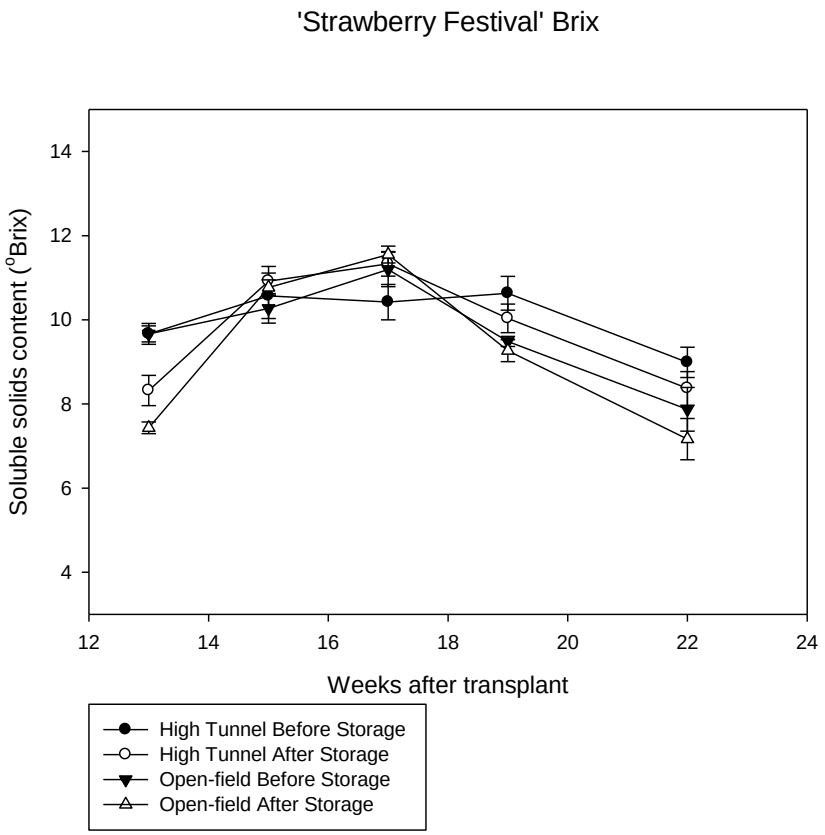

Figure 3-38. Effects of production systems on 'Strawberry Festival' strawberry soluble solids content before and after 8 days storage at 7.2°C in five different storage tests. 2008-09 Season.

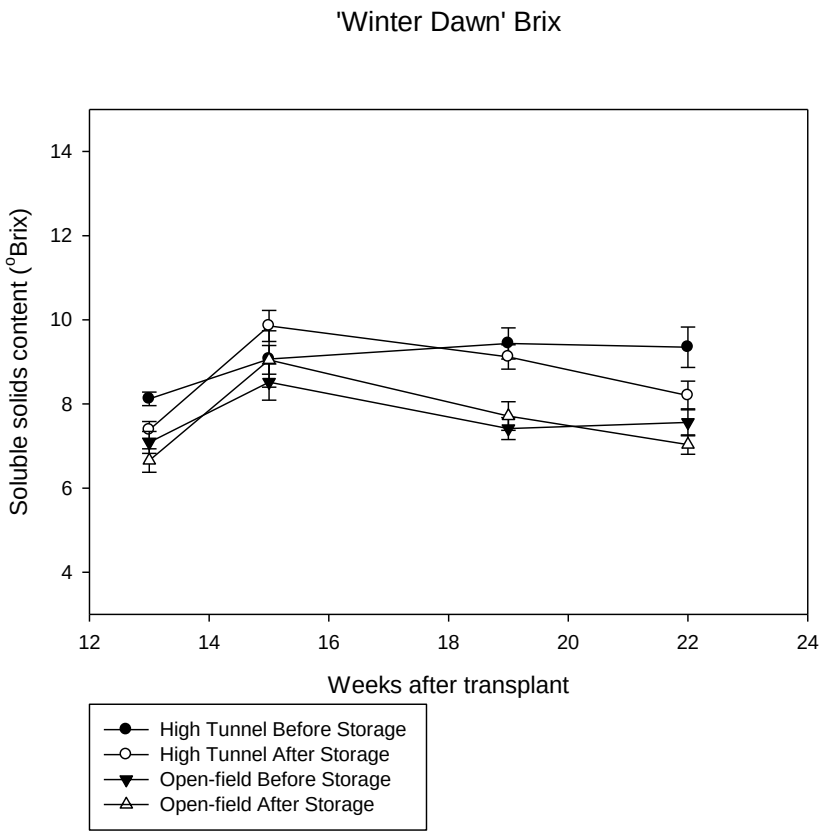

Figure 3-39. Effects of production systems on 'Winter Dawn' strawberry soluble solids content before and after 8 days storage at 7.2°C in four different storage tests. 2008-09 Season.

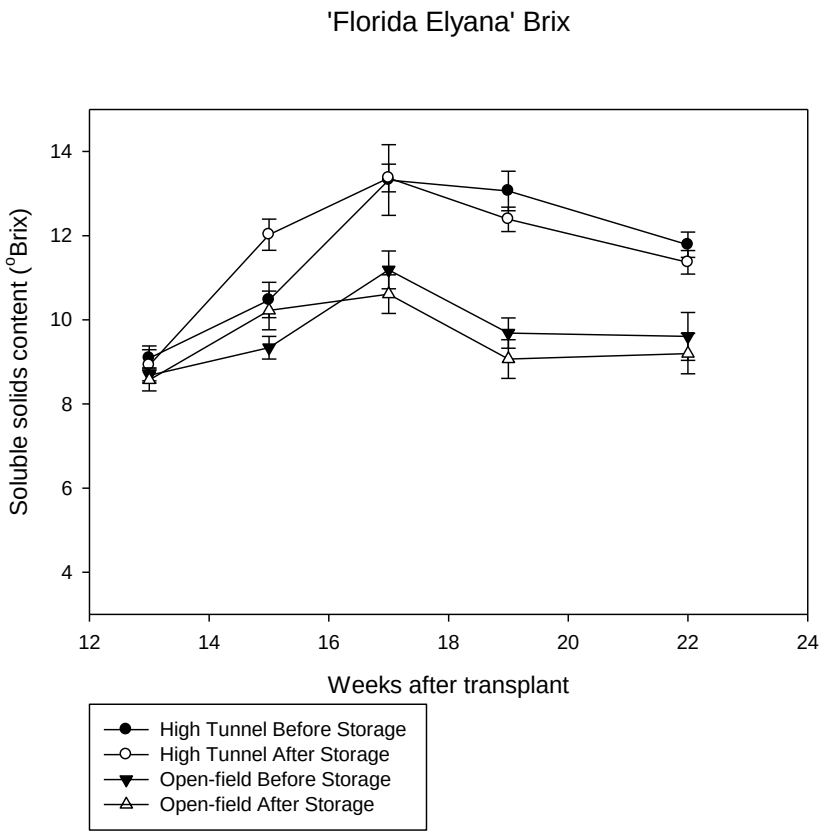

Figure 3-40. Effects of production systems on 'Florida Elyana' strawberry soluble solids content before and after 8 days storage at 7.2°C in five different storage tests. 2008-09 Season.

CHAPTER 4
SUMMARY AND CONCLUSIONS

The use of high tunnels in Florida might have several benefits to growers, such as early production, which might provide a competitive edge in the market. During the 2007-08 season, 'Strawberry Festival' yield was 440 kg/ha higher inside the high tunnels compared with the open field for the the first five harvests. Considering a 5.5 kg strawberry tray, inside the tunnels, there were 80 extra trays produced, and assuming a $30 per tray (average December price), additional $2,400 per hectare would be gross earned.

Since high tunnels are protected structures, they could allow growing other crops or cultivars, which might be susceptible to rain or low temperatures. Flowers are protected from early frost damage, and fruit are protected from rain damage. In this study, 'Florida Elyana', a strawberry cultivar susceptible to cracking, performed well under tunnel culture. Direct field observations indicated that the protection given by high tunnels decreased the incidence of some diseases, such as anthracnose fruit rot, botrytis fruit rot, and bacterial angular leaf spot, resulting on decreased pesticide use. Higher strawberry yield has been reported inside tunnels compared with open fields (Kader et al., 2006). Improvement of postharvest quality including higher soluble solids content, and higher vitamin C content in strawberry have been also reported (Voca et al., 2007).

High tunnels also have some limitation to be used in Florida, as mention above tunnels might protect plants from diseases, but also at the Research Center at Balm higher incidence of powdery mildew (*Sphaerotheca macularis*), two spotted spider mites (*Tetranychus urticae*) and chili thrips (*Scirtothrips dorsalis*) were found on the tunnels compared with the open field. Cost of installation and maintenance of high tunnels need to be considered, including the labor to install the structure and open and close the walls when the temperatures raise or drop, and also

the opportunity of opening and closing of high tunnels might influence the results and need to be studied. The occurrence of hurricanes in Florida is another limitation to high tunnels use. A hurricane can destroy the plastic or the whole tunnel structure, which means to replace the plastic or build a new tunnel for the following season with all the costs involved. Another barrier to the implementation of high tunnels in Florida is that conventional growers have been growing their crops, in this case strawberry following the same cultural practices for generations. In general growers are not willing to change a system that is well known for them.

In synthesis, the results from the two experiments conducted at the Gulf Coast Research and Education Center in Balm were similar in some aspects and different in others.For both seasons, strawberry plants grown inside the high tunnel were equal or wider than plants in the open field. A cultivar effect was observed for ’Strawberry Festival’ which show wider plants than ‘Winter Dawn’ and ‘Florida Elyana’. Also, production system effect was significant different on early yields and total yields. Strawberry yields inside the high tunnel were greater than yields in open field. Cultivar effects for different varieties showed that ‘Strawberry Festival’ had the highest early yield and total yield, followed by ‘Winter Dawn’ and ‘Florida Elyana’. On marketable fruit percentage after storage production systems had significant effect for ‘Winter Dawn’ and ‘Florida Elyana’ where the marketable fruit percentage was higher on strawberry from inside the high tunnels than from the open field. On the other hand, for ‘Strawberry Festival’ the production systems had no effects on strawberry marketability after storage. Soluble solids content for ‘Winter Dawn’ and ‘Florida Elyana’ cultivars grown inside the high tunnel presented higher values compared to fruit grown at open field.

Some of the variables measured had different response depending of the season. For the 2007-08 season chlorophyll content was higher in open-field compared to high tunnel. While, for

the 2008-09 season, chlorophyll content was higher on high tunnel than open field. In the same way, cultivars affected significantly chlorophyll content. However, in overall independently of the production system and the cultivar chlorophyll content were sufficient for the normal development of the strawberry crop. On the season 2007-08 the strawberry yield after freeze inside the high tunnel was greater than in open field. 'Strawberry Festival' had the highest yield followed by 'Winter Dawn' and 'Florida Elyana'. However, for the season 2008-09 the interaction between factors had effects on strawberry yield after the three freezes occurred. 'Strawberry Festival' inside the high tunnel had the highest yield; 'Winter Dawn' and 'Florida Elyana' in open field had the lowest yield for all the freezes. In general for the three cultivars on the 2007-08 season lightness values were lower for strawberry fruit before storage and higher after storage. However, for the 2008-09 season lightness values were higher for strawberry fruit before storage and lower after storage. This difference might be due to changes in handling of the fruit. For the 2007-08 season fruit was harvested in Balm at the Research Center, and transported to Gainesville to the Horticultural Department, to be processed next day. While, for 2008-09 season fruit was harvested and processed during the same morning at the Research Center in Balm. Chroma values in all the cultivars showed no difference when analyzed by production system, but in most cases values were higher before storage. Hue angle value did not present a clear trend effect for both production systems and cultivars, and in most cases hue angle values before storage were lower than hue angle values after storage.

In general, soluble solids content was higher on fruit from inside the high tunnels, compared with the open field, this differences was superior for 'Florida Elyana'. Comparing soluble solids content value from both seasons the first season had lower soluble solids content than the second season, which might be due to a variation during the sample processing and

preparation. Samples collected during the 2007-08 season were frozen, and stored until the end of the season. After that samples were defrosted, blended, centrifuged, filtered and evaluated for soluble solids content (°Brix), while for the 2008-09 season, the fruit was harvest, cut and squeezed and evaluated. Freezing the sample may a dilute it, if ice get inside the bag, centrifuge and filter might take some solids and as result the reading could be diminish.

Postharvest data collected during the 2007-08 season, showed that production systems had no effects on firmness value for strawberry fruit before and after storage for the three cultivars. Firmness values were higher after storage, compared with the values before storage. This might be explained because the sampling method is destructive. Fruit is cut and destroyed to be measured. Moreover, a different fruit was measure after storage, and that fruit could be in a different maturity stage.

Total titratable acidity was not affected by either of the production systems, but different cultivars presented significant different acidity values on most of the sampling dates. The highest acidity level was found on 'Winter Dawn', and the lowest on 'Florida Elyana'. 'Strawberry Festival' range between the other two cultivars. In most cases acidity levels were higher before storage than after storage. Again, this might be due to use of different fruit to measure acidity.

Vitamin C content was affected by both, the production systems and the different cultivars. Fruit from inside the high tunnel had equal or higher vitamin C content than fruit from open field. On cultivars, 'Strawberry Festival' had the highest vitamin C content and the lowest on 'Florida Elyana', 'Winter Dawn' had a value between the other cultivars. For the entire sample collected, strawberry fruit after storage have lower vitamin C than fruit before storage.

With the information discussed above it is possible to conclude that the use of high tunnels, for environmental conditions present at the Research Center (Balm, Florida) or other

surrounding locations, could help growers to increase plant diameter, improve early yields and total yields, and increase soluble solids content for some cultivars. Protected conditions could also allow the production of other crops or cultivar susceptible to low temperatures or rain. High tunnels structures serve as frost protection, and as result the water saving can be up to 600,000 L/ha of water per night of low temperatures, considering both strawberry seasons in this study there were 6 nights with low temperatures (3,600,000 L/ha of water). High tunnels can improve water conservation and reduce energy costs. Further studies need to be conducted to determine more effects of the high tunnels on the postharvest quality of the fruit, the effects of the high tunnels on other cultivars and other crops, intercropping systems to optimize the use of the high tunnels, and also a detailed economical study to determine the feasibility of using this production system.

APPENDIX A
TEMPERATURE DATA FROM FAWN WEATHER REPORT FOR BALM, FLORIDA DURING 2007-08 AND 2008-09 SEASONS

Table A-1. Daily average of data from FAWN weather report taken at 60 cm from soil, for Balm during 2007-08 season.

Date	Average	Minimum	Maximum
	(^{o}C)		
15-Oct-07	24.0	18.0	31.4
16-Oct-07	24.9	19.2	31.1
17-Oct-07	25.7	19.7	33.8
18-Oct-07	26.3	21.1	33.3
19-Oct-07	26.0	20.9	32.4
20-Oct-07	24.1	21.8	26.9
21-Oct-07	25.4	22.4	31.4
22-Oct-07	27.2	24.2	33.1
23-Oct-07	26.5	22.3	32.7
24-Oct-07	22.4	20.4	24.2
25-Oct-07	20.8	17.8	23.7
26-Oct-07	22.2	17.8	28.2
27-Oct-07	23.8	22.1	27.2
28-Oct-07	24.1	20.6	29.4
29-Oct-07	23.4	21.0	27.0
30-Oct-07	22.8	20.7	26.3
31-Oct-07	24.8	22.2	29.6
1-Nov-07	24.6	22.1	29.2
2-Nov-07	22.8	16.9	29.3
3-Nov-07	18.7	11.4	25.4
4-Nov-07	17.7	9.3	27.3
5-Nov-07	17.5	10.0	25.8
6-Nov-07	18.2	11.5	27.1
7-Nov-07	16.0	10.9	23.5
8-Nov-07	14.9	7.3	23.9
9-Nov-07	15.3	7.8	23.8
10-Nov-07	15.3	5.6	25.5
11-Nov-07	17.3	8.8	26.2
12-Nov-07	19.1	13.5	27.4
13-Nov-07	20.4	14.9	28.3
14-Nov-07	20.3	14.0	28.3
15-Nov-07	19.5	11.8	27.0
16-Nov-07	11.2	4.7	18.4
17-Nov-07	14.1	4.8	25.0
18-Nov-07	17.6	9.0	26.7
19-Nov-07	19.7	14.3	27.1
20-Nov-07	20.2	14.3	27.9

21-Nov-07	19.7	13.2	27.9
22-Nov-07	20.7	14.5	26.9
23-Nov-07	19.7	14.7	24.0
24-Nov-07	19.2	11.7	27.6
25-Nov-07	22.7	17.6	29.5
26-Nov-07	22.3	17.8	29.2
27-Nov-07	21.9	16.1	29.2
28-Nov-07	22.5	17.5	29.0
29-Nov-07	22.0	17.5	27.5
30-Nov-07	20.1	17.6	23.5
1-Dec-07	20.7	15.6	28.6
2-Dec-07	21.9	15.9	30.5
3-Dec-07	21.1	13.8	27.7
4-Dec-07	14.7	6.5	21.5
5-Dec-07	13.4	4.4	22.8
6-Dec-07	16.7	9.4	27.2
7-Dec-07	19.7	11.1	29.6
8-Dec-07	22.0	16.8	28.6
9-Dec-07	21.8	15.3	28.4
10-Dec-07	21.6	16.4	29.5
11-Dec-07	22.1	16.5	29.2
12-Dec-07	21.6	15.8	28.9
13-Dec-07	21.6	14.9	30.0
14-Dec-07	22.2	17.9	27.6
15-Dec-07	24.1	21.5	28.7
16-Dec-07	18.9	8.5	24.1
17-Dec-07	7.5	2.3	14.2
18-Dec-07	12.4	3.4	22.7
19-Dec-07	16.8	9.6	25.3
20-Dec-07	18.0	11.0	26.4
21-Dec-07	18.7	13.1	23.7
22-Dec-07	15.3	10.7	18.8
23-Dec-07	18.7	14.0	25.5
24-Dec-07	18.8	15.0	26.0
25-Dec-07	19.1	14.1	26.9
26-Dec-07	17.0	12.8	23.6
27-Dec-07	19.2	12.0	28.7
28-Dec-07	21.6	15.7	29.0
29-Dec-07	21.4	16.5	28.9
30-Dec-07	22.5	16.9	28.2
31-Dec-07	21.9	17.4	26.4

1-Jan-08	19.1	9.9	22.8
2-Jan-08	6.1	0.0	10.5
3-Jan-08	4.4	-2.6	12.5
4-Jan-08	10.6	3.2	19.6
5-Jan-08	15.0	8.4	23.3
6-Jan-08	18.0	13.0	26.3
7-Jan-08	19.6	13.0	27.1
8-Jan-08	19.7	14.0	27.7
9-Jan-08	18.3	9.5	27.8
10-Jan-08	19.4	13.9	28.0
11-Jan-08	19.4	12.1	27.3
12-Jan-08	20.5	13.7	28.7
13-Jan-08	20.7	14.7	27.1
14-Jan-08	13.6	7.2	18.7
15-Jan-08	10.5	2.9	18.8
16-Jan-08	16.3	8.6	23.6
17-Jan-08	20.4	17.1	24.0
18-Jan-08	17.7	16.3	19.2
19-Jan-08	20.4	15.8	27.3
20-Jan-08	10.4	6.1	15.3
21-Jan-08	13.5	4.6	23.0
22-Jan-08	19.9	13.1	27.3
23-Jan-08	20.8	16.3	26.4
24-Jan-08	17.5	13.5	21.8
25-Jan-08	13.6	7.0	20.2
26-Jan-08	15.2	8.2	22.0
27-Jan-08	15.8	9.3	20.5
28-Jan-08	11.3	4.0	20.7
29-Jan-08	14.0	2.7	24.3
30-Jan-08	19.5	14.0	26.6
31-Jan-08	19.7	11.9	27.8
1-Feb-08	18.1	9.5	24.8
2-Feb-08	16.9	5.8	29.0
3-Feb-08	19.8	11.9	28.5
4-Feb-08	20.9	14.7	29.5
5-Feb-08	20.5	14.2	29.7
6-Feb-08	21.3	13.8	27.8
7-Feb-08	22.7	18.4	28.9
8-Feb-08	20.7	16.2	25.7
9-Feb-08	17.7	13.1	21.6
10-Feb-08	16.0	7.8	23.9

11-Feb-08	15.1	4.5	24.5
12-Feb-08	18.1	12.1	24.3
13-Feb-08	18.8	11.5	23.5
14-Feb-08	11.9	3.7	21.4
15-Feb-08	16.3	7.7	25.9
16-Feb-08	18.7	11.2	27.4
17-Feb-08	21.2	14.4	29.3
18-Feb-08	21.7	16.3	28.6
19-Feb-08	16.3	9.8	22.5
20-Feb-08	15.2	6.7	22.1
21-Feb-08	20.4	14.5	27.5
22-Feb-08	23.0	18.8	29.2
23-Feb-08	22.0	18.8	27.7
24-Feb-08	20.2	15.3	25.5
25-Feb-08	21.1	16.4	26.8
26-Feb-08	23.1	17.0	28.4
27-Feb-08	12.8	4.2	20.0
28-Feb-08	8.8	1.6	16.9
29-Feb-08	13.5	3.0	23.3
1-Mar-08	17.3	9.5	25.6
2-Mar-08	18.4	10.8	26.8
3-Mar-08	20.5	11.5	28.9
4-Mar-08	21.9	18.8	25.7
5-Mar-08	19.3	15.5	23.7
6-Mar-08	17.5	11.8	25.2
7-Mar-08	23.1	17.1	30.0
8-Mar-08	15.5	5.9	20.5
9-Mar-08	12.2	3.7	20.5
10-Mar-08	17.5	10.4	24.5
11-Mar-08	20.5	16.1	25.9
12-Mar-08	19.0	13.1	23.8
13-Mar-08	17.2	8.5	25.9
14-Mar-08	17.1	15.6	20.1
15-Mar-08	22.2	14.7	29.0
16-Mar-08	24.5	17.1	30.5
17-Mar-08	21.3	16.5	28.4
18-Mar-08	21.7	15.7	28.4
19-Mar-08	23.3	18.0	29.9
20-Mar-08	20.7	11.3	25.6
21-Mar-08	18.8	10.7	27.3
22-Mar-08	18.4	14.8	21.4

23-Mar-08	21.6	16.6	28.0
24-Mar-08	16.7	10.0	21.7
25-Mar-08	12.8	4.0	21.0
26-Mar-08	16.1	8.5	24.5
27-Mar-08	18.6	9.4	27.6
28-Mar-08	13.5	13.5	13.5

Table A-2. Daily average of data from FAWN weather report taken at 60 cm from soil, for Balm during 2008-09 season.

Date	Average	Minimum	Maximum
	(^{o}C)		
15-Oct-08	24.0	17.7	31.0
16-Oct-08	23.2	17.8	31.0
17-Oct-08	23.4	16.6	32.2
18-Oct-08	22.9	16.1	29.7
19-Oct-08	20.0	13.3	27.5
20-Oct-08	21.1	15.4	29.2
21-Oct-08	21.7	16.0	29.3
22-Oct-08	22.8	17.0	28.8
23-Oct-08	24.0	21.0	28.5
24-Oct-08	23.5	20.7	27.6
25-Oct-08	23.8	18.8	28.4
26-Oct-08	19.4	13.0	27.2
27-Oct-08	18.8	10.7	27.6
28-Oct-08	12.0	6.0	18.1
29-Oct-08	11.0	1.6	20.1
30-Oct-08	14.6	5.0	24.0
31-Oct-08	18.3	12.3	26.3
1-Nov-08	18.4	13.8	25.5
2-Nov-08	19.4	17.4	25.7
3-Nov-08	21.0	17.0	28.0
4-Nov-08	18.2	16.5	20.2
5-Nov-08	17.7	16.0	19.4
6-Nov-08	19.1	12.7	27.5
7-Nov-08	19.8	12.0	29.1
8-Nov-08	19.9	12.4	27.3
9-Nov-08	17.1	10.0	25.4
10-Nov-08	16.4	8.2	25.6
11-Nov-08	19.3	11.5	28.2
12-Nov-08	23.3	17.6	30.7
13-Nov-08	25.1	20.6	31.9

14-Nov-08	24.5	19.7	32.2
15-Nov-08	22.7	17.9	27.6
16-Nov-08	12.4	3.2	17.9
17-Nov-08	11.0	2.6	20.3
18-Nov-08	13.3	6.8	21.9
19-Nov-08	9.4	2.2	18.6
20-Nov-08	10.9	0.8	21.4
21-Nov-08	14.1	6.1	23.8
22-Nov-08	11.8	4.5	21.2
23-Nov-08	13.9	7.4	23.2
24-Nov-08	16.1	9.6	25.6
25-Nov-08	15.0	7.8	23.9
26-Nov-08	12.4	2.8	23.0
27-Nov-08	11.1	0.6	23.4
28-Nov-08	13.4	3.3	26.3
29-Nov-08	17.3	6.4	27.4
30-Nov-08	18.6	15.2	25.2
1-Dec-08	16.5	11.9	20.6
2-Dec-08	11.7	2.1	17.0
3-Dec-08	11.0	1.3	21.7
4-Dec-08	16.2	8.8	26.0
5-Dec-08	16.7	8.1	26.5
6-Dec-08	17.2	9.3	24.4
7-Dec-08	14.2	6.2	19.9
8-Dec-08	13.4	3.0	24.5
9-Dec-08	19.3	10.3	28.1
10-Dec-08	22.5	18.8	29.4
11-Dec-08	19.9	16.5	22.3
12-Dec-08	14.4	8.2	18.3
13-Dec-08	11.7	3.0	20.4
14-Dec-08	17.8	10.9	25.5
15-Dec-08	20.2	17.8	25.1
16-Dec-08	19.9	13.6	27.4
17-Dec-08	20.5	14.6	27.6
18-Dec-08	20.2	14.7	27.6
19-Dec-08	18.7	12.5	27.5
20-Dec-08	16.7	11.0	25.2
21-Dec-08	17.5	9.6	26.1
22-Dec-08	12.6	6.7	17.3
23-Dec-08	15.1	6.1	24.8
24-Dec-08	21.6	15.2	28.2

25-Dec-08	22.7	20.1	27.5
26-Dec-08	21.9	17.1	28.7
27-Dec-08	20.2	14.4	27.7
28-Dec-08	19.9	13.2	28.1
29-Dec-08	19.4	12.4	26.9
30-Dec-08	18.0	7.4	26.0
31-Dec-08	15.0	5.4	24.2
1-Jan-09	15.3	8.4	22.9
2-Jan-09	17.9	12.8	26.3
3-Jan-09	18.1	11.1	26.0
4-Jan-09	19.5	13.1	27.5
5-Jan-09	19.7	13.8	29.3
6-Jan-09	20.2	12.7	28.7
7-Jan-09	18.1	6.8	24.9
8-Jan-09	13.3	4.0	22.1
9-Jan-09	13.7	6.3	24.1
10-Jan-09	15.8	7.5	26.7
11-Jan-09	17.6	9.5	26.2
12-Jan-09	17.7	15.2	20.8
13-Jan-09	15.7	10.3	25.9
14-Jan-09	11.2	1.7	21.2
15-Jan-09	8.5	2.3	15.4
16-Jan-09	10.0	4.7	17.5
17-Jan-09	9.3	1.6	19.0
18-Jan-09	12.3	2.6	22.6
19-Jan-09	16.7	10.0	20.8
20-Jan-09	11.3	5.1	17.6
21-Jan-09	4.2	-3.3	11.1
22-Jan-09	5.5	-4.7	18.1
23-Jan-09	9.8	-2.1	23.0
24-Jan-09	12.7	2.4	22.7
25-Jan-09	15.5	5.6	26.3
26-Jan-09	18.2	9.0	27.5
27-Jan-09	20.2	13.2	28.2
28-Jan-09	21.4	16.8	28.6
29-Jan-09	21.0	16.7	27.1
30-Jan-09	14.1	8.8	18.8
31-Jan-09	8.9	1.7	17.6
1-Feb-09	11.8	1.4	21.3
2-Feb-09	16.0	11.8	19.4
3-Feb-09	12.2	3.0	15.8

4-Feb-09	7.4	1.1	13.6
5-Feb-09	3.8	-2.7	12.6
6-Feb-09	8.7	-1.4	20.3
7-Feb-09	12.7	4.6	22.6
8-Feb-09	14.8	6.7	24.4
9-Feb-09	15.5	5.4	25.4
10-Feb-09	17.5	9.0	27.6
11-Feb-09	20.3	11.9	29.2
12-Feb-09	20.4	16.6	26.8
13-Feb-09	19.9	12.8	29.8
14-Feb-09	17.3	9.8	24.9
15-Feb-09	20.2	15.8	26.7
16-Feb-09	18.4	8.9	24.3
17-Feb-09	14.1	5.6	24.1
18-Feb-09	17.0	7.5	24.9
19-Feb-09	18.1	15.1	24.3
20-Feb-09	12.5	3.2	18.7
21-Feb-09	12.0	-0.2	24.5
22-Feb-09	16.3	7.7	24.7
23-Feb-09	15.4	8.7	23.6
24-Feb-09	14.5	5.0	24.8
25-Feb-09	17.0	9.9	25.6
26-Feb-09	17.0	8.6	25.9
27-Feb-09	18.0	9.8	28.4
28-Feb-09	19.0	9.8	28.6
1-Mar-09	15.0	10.1	20.1
2-Mar-09	10.0	2.4	14.8
3-Mar-09	9.5	1.0	19.2
4-Mar-09	12.6	3.1	23.2
5-Mar-09	16.2	7.4	25.1
6-Mar-09	17.4	7.9	27.0
7-Mar-09	17.9	8.1	28.5
8-Mar-09	18.8	8.8	28.5
9-Mar-09	19.4	9.8	28.7
10-Mar-09	19.8	10.1	30.9
11-Mar-09	20.3	10.0	31.5
12-Mar-09	20.1	11.0	29.9
13-Mar-09	21.6	14.5	29.2
14-Mar-09	21.9	15.4	30.5
15-Mar-09	22.5	15.9	30.9
16-Mar-09	22.2	15.0	30.0

17-Mar-09	20.6	14.7	26.8
18-Mar-09	21.6	16.6	28.8
19-Mar-09	21.1	15.2	28.8
20-Mar-09	20.2	11.2	28.8
21-Mar-09	19.6	13.2	27.9
22-Mar-09	17.7	11.1	25.1
23-Mar-09	17.1	14.0	21.0
24-Mar-09	19.3	10.7	27.9
25-Mar-09	20.1	11.0	28.5
26-Mar-09	21.6	14.7	29.8
27-Mar-09	22.3	16.1	30.2
28-Mar-09	25.2	20.6	31.7
29-Mar-09	20.5	11.2	24.5
30-Mar-09	18.7	7.4	30.1

APPENDIX B

EFFECTS OF PRODUCTION SYSTEM ON STRAWBERRY PH ON STRAWBERRY FRUITS BEFORE AND AFTER 8 DAYS STORAGE AT 7.2^{O}C IN FIVE DIFFERENT STORAGE TESTS ON 2007-08 SEASON

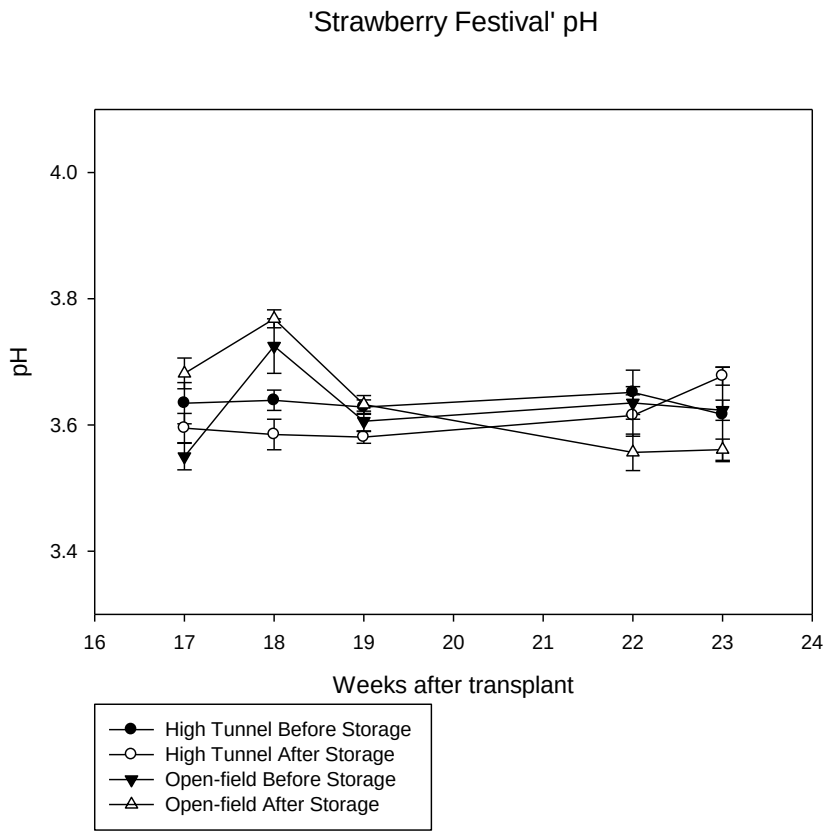

Figure B-1. Effects of production system on strawberry pH on 'Strawberry Festival' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2007-08 Season.

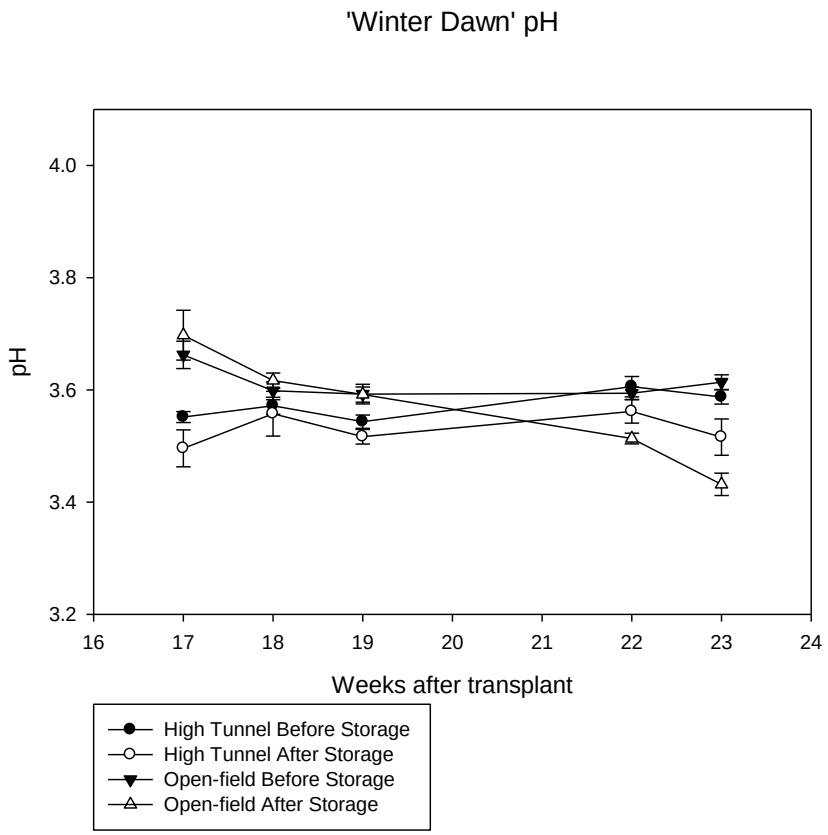

Figure B-2. Effects of production system on strawberry pH on 'Winter Dawn' strawberry before and after 8 days storage at 7.2^{o}C in five different storage tests. 2007-08 Season.

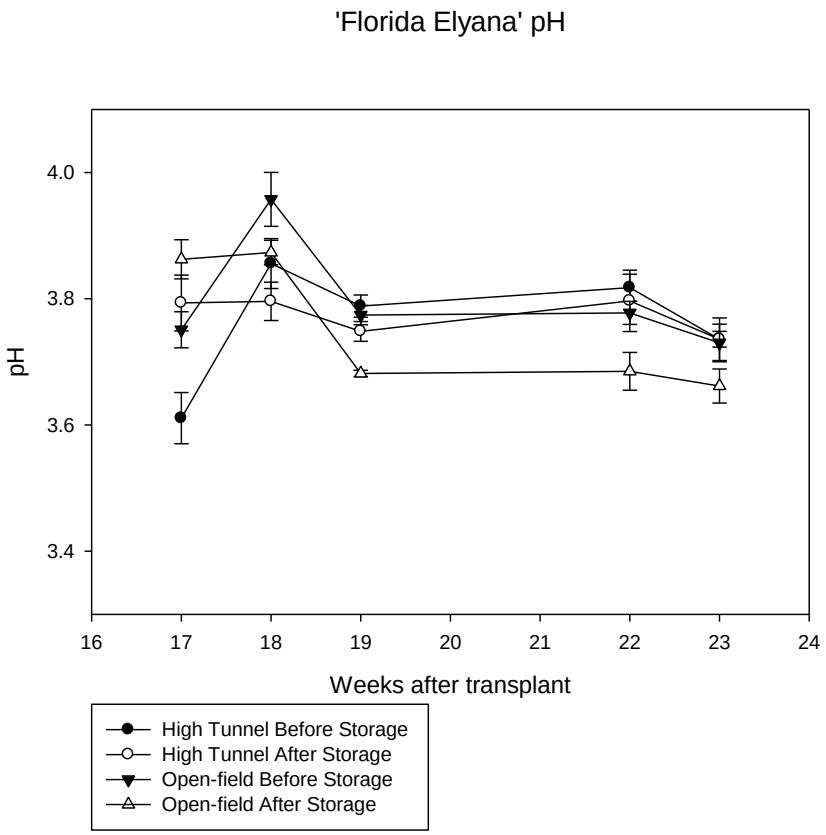

Figure B-3. Effects of production system on strawberry pH on 'Florida Elyana' strawberry before and after 8 days storage at 7.2°C in five different storage tests. 2007-08 Season.

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BIOGRAPHICAL SKETCH

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