Pre-harvest effects on postharvest quality of spring-planted, day-neutral strawberries in high tunnel system

by

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Abstract

Intensive specialty crop production within high tunnel systems in the central U.S. has greatly expanded. High tunnel systems, used primarily to protect specialty crops from harsh environmental conditions, improve marketability, and extend fruiting season. High tunnel day-neutral strawberry (*Fragaria x ananassa*) production in Kansas may by limited due to the high summer temperatures. Evaporative cooling within a high tunnel is a novel technique meant to cool the plant temperature during the hottest months of production. Currently, evaporative cooling is implemented in the early stages during the heavy bloom period. Spring-planted day-neutral strawberry production within high tunnels could provide growers with enhanced yields and marketability, improved storage quality, and late-season prices. This study identifies the optimum cultivars in a plasticulture, high tunnel system with the use of evaporative cooling in regards to yield, quality, storage life, and consumer opinion. The trial was conducted at the Kansas State University Olathe Horticulture Research and Extension Center (OHREC) during 2014 and 2015. Six commercially-available cultivars were evaluated: 'Albion', 'Evie 2', 'Monterey', 'Portola', 'San Andreas', and 'Seascape'. Mature fruit (90-100% red) were harvested twice a week and four harvests were evaluated for at harvest and postharvest quality throughout each production year. Storage life was monitored every 24hrs by respiration rate, moisture content and overall visual quality, using a scale from 5 (excellent) to 1 (very poor). Physical and organoleptic quality measurements (texture and color, and soluble solids and titratable acidity) were evaluated every two days throughout storage, and nutritional quality (total phenolic and antioxidant availability) was evaluated at harvest. Our results indicate that 'Portola' had the highest yields in 2014 and 2015 at 1.33 lbs/plant and 1.12 lbs/plant, respectively. At harvest, the soluble solids content (°Brix) was highest with 'Monterey' and 'Albion' (P <

0.0001), while ‘San Andreas’, ‘Monterey’, ‘Portola’, and ‘Albion’ retained firm texture (force(g)) ($P \leq 0.0001$). All cultivars maintained their overall visual quality until day 8, with the exception of ‘Evie 2’ and ‘Seascape’. Furthermore, the four cultivars maintained visual quality and had lower respiration rates and moisture content loss ($P < 0.001$, $P < 0.0001$, $P < 0.05$). Throughout storage, ‘Seascape’ had a high respiration rate ($P < 0.0001$) and low overall visual quality ($P < 0.01$). Moisture content loss (%) throughout 2014 storage life was less than in 2015 ($P < 0.0001$) and ‘San Andreas’ and ‘Monterey’ had the least moisture loss throughout both production seasons ($P < 0.01$). In our trials, evaporative cooling did not affect yield or the incidence of disease. However, the use of evaporative cooling resulted in lower total phenolic levels in both production years ($P < 0.0001$), and higher respiration rates during storage, as observed in 2015 ($P \leq 0.01$). Because of significant year-to-year differences in berry weight (lbs/plant) and size (oz/fruit), further studies are needed to identify the weather effect and best management practices in the region. In Kansas, growing day-neutral strawberries in a high tunnel has potential based on yield and quality of the fruit that we evaluated.

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Chapter 1 - Review of the Literature

Importance of Local Food Production in the United States

It has been reported that fruit, vegetables, and nuts account for the greatest proportion (51%) of all local food sales (Low et al., 2015). Of all production categories, fruit and nut production is reported as the greatest local production category per farm, averaging $25,000 (USDA-NASS, 2012). Additionally, farms involved in direct-to-consumer (DTC) markets are oftentimes small scale (<$50,000 in annual sales). Most DTC small-scale operation are located near urban and peri-urban areas who account for 89% of all DTC sales (USDA-NASS, 2007). There was a 64% increase in DTC farms exceeding $50,000 in annual sales from 2002-2007, with fruit and tree nut DTC farms increasing 75% in the same time (USDA-ERS, 2010).

This data indicates that the local food production could be an important part in feeding city populations. However, food-security concerns for healthy food access is not the only reason of the increasing interest in local food in the U.S. It is also a culmination of several environmental movements: the desire to challenge large food industry sectors, the "slow-food" movement, and general knowledge expansion (Gaytan, 2003; Pirog and McCann, 2009). These movements encourage dietary guidance of seasonal eating rather than food groups alone, which result in diet diversity. The Food Marketing Institute (FMI, 2014) surveyed a varied U.S. consumer population (n=2000) and found that in order of importance: freshness, support of the local economy, and taste were the most frequent reasons for buying local food. The food system in a particular community is often studied as an indicator of health quality related to the dietary patterns (Abate, 2008). The relationship between freshness and health is apparent and widespread, as there is an ever-greater focus on health optimization from fresh food. The proximity of food source and nutritional quality are also related and Shewfelt (1990) describes the relationship between transportation and nutritional quality loss. In the report, 5-10 days of transportation resulted in 30-50% of some nutritional constituents. Local food production could be a solution for providing fresh and nutritious food to communities in city centers.

One of the most debated questions that arises is how to define “local food”. Local food is typically defined based on distance, but tends to vary subjectively. Whole Foods varies on the definition from store-to-store. It can range from a day-lengths drive away by semi-truck (<8 hours), or within the state or region boundaries (Martinez, 2010). The 2008 Farm Act defines “Locally or regionally produced agricultural food product,” as food traveling less than a distance of 400 miles from its origin. The Iowa State extension program specialist, Andrew Larson, surveyed customers to define local food. He determined stricter definitions: “[local food is] food that was produced or grown in your home county or a neighboring county,” or “food that was produced or grown within 100 miles.” (Sager, 2008). The Leopold Center for Sustainable Agriculture said that the 100-mile definition was most widely accepted (Sager, 2008).

However local food is defined, it is obvious that over the last decade, an increase in per capita consumption has led to significant increases in sales for the local produce industry (USDA-NASS, 2012). Producer participation in local food systems, as well as the value of local food sales, including both DTC (e.g. Farmers’ markets) and intermediate marketing channels (e.g. sales to institutions or regional distributors) is increasing (USDA-NASS, 2007). The Census of Agriculture resource and Management Survey (ARMS) estimated $6.1 billion in local food sales in 2012, which only accounts for DTC sales. Intermediate marketing channels include a large percentage (~30%) of the foodservice market through independently owned grocery stores specializing in local food, food distributors, consumer-owned retail food cooperatives, food hubs, etc. (Low et al., 2015). Tom Vilsack, USDA's agriculture secretary, estimates "the value of the local food was nearly $12 billion in 2014," which includes both DTC and intermediate sales. The surveyed data on locally grown and sold foods will be included in the next agricultural census (Young, 2016).

Smith (2009) observed that since the early 2000's, large supercenters took notice in a shift of consumer perspective towards local food, introducing "local food aisles" and opening specialty plants to meet the demand. Federal policies related to local and regional food systems were greatly expanded by the Food, Conservation, and Energy Act of 2008, and are further expanded in the Agriculture Act of 2014, which strengthened support for intermediated marketing channels. Even supercenters, such as Wal-Mart, have committed to local food initiatives sourcing 20% of its produce locally within season and granting funding to projects like NSSI. $400 million is spent on local produce in the summer months at Wal-Mart. Whereas Safeway, the fifth-largest U.S. food retailer, commits to 30% of its in-produce is locally sourced within season (Martinez, 2010). Data collected from the 2007 Census of Agriculture and USDA's Agriculture Marketing Service has found that expanding local food systems in a community can increase employment and income in the community, and provides the capability of reducing energy and greenhouse gas utilization (USDA-NASS, 2007; Low et al., 2015). In conclusion local food production can be recognized as an important part in feeding city populations (USDA-NASS, 2007); as an economic revival strategy in many cities across the U.S. (Cantrell et al., 2008); as a public health strategy to improve nutrition (Shewfelt et al., 1990); and as a strategy for community development (Pirog and McCann, 2009).

Challenges and Solutions with Local Production

The increasing demand of local food is certainly a positive result of the recent emphasis on addressing food security for the growing population. However, meeting the consumers demand for locally grown fresh products could be challenging. Many of the DTC markets tend to be operated by small-scaled beginning farms with less than ten years of operation that are not able to meet the product volume that is required in order to scale up their farms. For local producers, it can be difficult to meet consumer demand and expectation for high volumes, consistent quality, timely deliveries, and out-of-season availability (Abate, 2008; Gregoire et al., 2005). Intermediate markets such as regional food hubs address some of the obstacles. According to the 2013 National Food Hub Survey, 76% of food hubs work with farms producing less than $500,000 annually, and 26% of the producers have less than 10 years of experience (Fischer, 2013). By creating a centralized distribution and storage center, food hubs address the concern for product volume by concentrating many farmer's products. This alleviates farmer's responsibilities who no longer require on-farm infrastructure, marketing and distributing practices (Fischer, 2013). The 2014 Farm Bill supports beginning farmers by increasing 'The Beginning Farmers and Ranchers Development Program' to $100 million, and reduces crop insurance premiums during the first 5 years of farming (Chite, R.M., 2014). These new mandates will lessen the burden of DTC growers trying to penetrate new markets while operating on small-scales. Communication between growers and buyers is often challenged by high demands and variable yields. Starr et al. (2003) expands upon complaints between restaurants and growers in Colorado. They find it challenging to operate a restaurant with a seasonal menu while collaborating with multiple small growers for the same commodity in order to reach high volume requirements. Gregoire et al. (2005) used a questionnaire to assess the greatest obstacles experienced by local food producers from Iowa (n=560). Tomato producers made up the largest proportion of those selling in DTC channels who said a large barrier exists with production quantity and buyer receptiveness. Grower-to-grower collaboration is fundamental to meet quantity needs while allowing growers to assess what is missing in a broader market place.

Lack of cost-effective infrastructure is another challenge because local food supply chains often lack distribution systems into mainstream markets. Infrastructure is often available to commercial growers with greater incomes operating on larger scales (Day-Farnsworth et al., 2009). Organization of the small-scaled producers could result in a shared cooler, warehouse, or distribution system to streamline DTC or intermediate market presence. In addition to The Beginning Farmers and Ranchers Development Program, the 2014 Farm Bill addresses infrastructure and distribution challenges experienced by local producers by expanding the "Farmers Market and Local Food Promotion Program" to $30 million annually.

Challenging yet, food-borne pathogen outbreaks of raw produce have become increasingly public; therefore, GAP certification is increasingly required by DTC or intermediate markets. Regulations for trace-back mechanisms, food labeling, and sanitary transportation of local food operations are all addressed under the 2011 FDA Food Safety Modernization Act (FSMA). FSMA addresses preventative approach with third-party audits, that cost thousands of dollars and require yearly renewals. However, the guidelines grant exceptions to farms selling less than $500,000 annually. GAP certification is not mandated but may be advantageous and help growers maintain market access. Grouped farming plans addresses the cost issues associated with third-party audits for GAP certification. The USDA started a pilot study for the group GAP project in Kansas City at the Good Natured Family Farms to standardize the operating procedures of auditing the group GAP certification as one entity (Low et al., 2015). The results show alleviation of the high cost audits while reviewing the on-farm safety plans of several small to medium sized growers. An example of an enterprise's solution to difficulties in distribution is Cherry Capital Foods in Wisconsin who distributes small farm production to wholesale market. Growers within their program are required to follow Good Agricultural Practices (GAP's), Hazard Analysis and Critical Control Points (HACCP) plans, and specification to packaging and traceability (Day-Farnsworth et al., 2009). GAP certification is beneficial with specialty crop production, especially in berry operations that are highly susceptible to decay because of their porous skin. For example, Woods et al. (2012) found that adoption of GAPs by organic strawberry growers nationally could open in-season marketing windows for smaller production areas. The model used focused on economic incentives of strawberry production with cost-saving benefits, reduction of product shrinkage, and small grower benefits with short-term production periods. They determined that growing 30% organic is the minimum for certified production as 30% of consumers regularly purchase organic strawberries. The model assumes a shrinkage of microbial pathogens and a prolonged shelf life with temperature and handling management.

Local Food Production in the Midwest

Data collected from the 2007 Census of Agriculture and USDA's Agriculture Marketing Service displays counties in the Midwest and South tend to have median DTC sales of $122,000 or less. Mono-crop production dominates the Midwest landscape, with the majority of large farms growing in the subsidized category of corn, soy, wheat, cotton, and rice. Data from the Environmental Working Group (EWG) database shows that the top 10 ranking states to receive subsidy payments are all within the Midwest section, with Kansas alone collecting 18.5 billion dollars annually. The large majority of the crops grown are used as the main energy ingredient in livestock feed, while also processed into a multitude of additives such as starch, sugars, oils, beverages, and fuel ethanol (USDA-ERS, 2016). Meaning that the majority of farmers are on the large industrial scale in the Midwest focus their efforts on the mono-crop production, leaving smaller-scaled farmers in the DTC channels to diversify production. The value of eating seasonally in the Midwest is difficult to teach consumers when supermarkets and grocery stores offer a variety of fresh imported produce throughout the year.

A common misconception is that local food tends to come at a higher price. Pirog and McCann (2009) compared local and non-local vegetable prices in Iowa, when local production is both in and out of peak season. The objectives of the study were to examine the food service operations and consumer perceptions. They found that the mean price per pound of local farmers' market vegetable basket in Iowa was $1.25 compared to the non-local supermarket vegetable basket at $1.39. The Nielsen Homescan Panel Data verified the difference in average prices for produce in DTC outlets versus mainstream grocers and supercenters in the North Central region of the U.S. The prices for common produce staples (e.g. tomatoes, potatoes, peppers, apples, and grapes) were all lowest at DTC outlets, and highest at grocery stores (Low et al., 2015). Educating consumers on their misconceptions could encourage more deliberate food shopping and local food consumption. A food hub feasibility study in Kansas City was conducted to assess the grower and buyer interest in local food sales. 43% of growers within a 250-mile radius were interested in selling locally. Of the top 10 crops of interest, apples, melons, and berries were the only fruit crops cited by local growers. However, very little berry production currently exists in the surrounding counties (KC Public Food Hub Feasibility Study, 2015).

Strawberry Plant

Generally speaking, strawberry (*Fragaria × ananassa)* is a widely grown hybrid species of the genus Fragaria (collectively known as the strawberries). Interestingly, strawberries are not an actual berry by the botanical definition but an aggregate accessory fruit. An accessory fruit is a fruit in which some of the flesh is derived not from the ovary but from some adjacent tissue, like in a strawberry. Strawberries contain phytochemicals to provide health benefits, and their colors are due to the natural plant pigments. It has positive effects on multiple diseases including inflammation and cancer and has shown in studies a characteristic aroma, bright red color, juicy texture, and sweetness (Yang et al., 2011).

Strawberries have a short stem called a "crown", and individual plants can produce branch crowns during the fall to increase plant yield. Main crowns and branch crowns are structurally identical, and specific cultivars tend to have varying crown development. Ideal crown development between 3-6 will encourage high yields with large fruit size. High temperatures encourage crown development (>6) which will potentially decrease fruit size. Petioles arrange themselves circularly around the crown and the leaf blades are divided into 3 leaflets, called a "trifoliate". This is the part of the plant responsible for photosynthesis, requiring water and CO_2 and translocate the carbohydrates from the leaf to storage or consumption. Timing of fall planting is a delicate procedure as a warm fall may encourage over development of crown growth, while an early fall freeze or poor irrigation during plant establishment will cause leaves to die. The number of leaves and total plant leaf area in the late fall/early winter can be correlated with fruit production the following spring. Greater canopy protection acts as a crown insulator during winter, and early-spring months. Roots anchor the plant, and capture water and soil nutrients. Most of the water taken up by the plant evaporates from the "stomata", and it is crucial for growers to supply adequate irrigation during plant establishment in the spring. Root growth is promoted when soil is ~55°F. The pistils are projected from the conic-shaped flower-supporting stem called the “receptacle”. The receptacle is fertilized and later matures into a strawberry. Achenes are the seed-like structures outside the berry with ovules that could potentially become seedlings. In order to continue producing the exact genotype, it is the runner plant that multiplies from the mother plant that contains the identical genetic makeup. Maturation of the fruit from open blossom to ripeness takes 20 to 30 days. (Barclay Poling, 2012).

Strawberries have health-promoting benefits as an antioxidant-rich food. Amongst other fruits, strawberries have a greater antioxidant capacity (2- to 11-fold) than apples, peaches, pears, grapes, tomatoes, oranges, or kiwifruit (Scalzo, et al., 2005; Wang et al., 1996). Antioxidant-rich foods inhibit oxidation of human low-density lipoproteins and aid in prevention of various human diseases caused by oxidative stress; strawberry extract reduces age-related motor and cognitive deficits in aged rodents (Ames et al., 1993 and Joseph et al., 1999). Joseph (1999) hypothesizes that the variation in brain cognitive effects exist between fruit and vegetables because of the interactions between available flavonoids and other phytochemicals present on antioxidant activity. Anthocyanin is the main antioxidant in strawberries and research has shown it to have greater activity than other common antioxidants such as ascorbate, glutathione, etc. Anthocyanins are a water-soluble vacuolar pigments that may appear red, purple, or blue depending on the fruit pH. Two anthocyanidins glycosides, pelargonidin 3-glucoside and cyanidin 3-glucoside are almost exclusively responsible for the red color of strawberries (Timberlake and Bridle, 1982). Variability was found amongst the anthocyanin concentrations in samples of the same cultivar and harvest date, indicating the strong influence of the degree of maturity, climatic factors, and postharvest storage on anthocyanins (Lopes da Silva et al., 2007). Phenolic acids make up the largest percentage of total phenolic content in strawberries, with Ellagic acid was the main phenolic compound. While flavonols represent 11% of phenolics in strawberry (Häkkinen et al. 1999).

Environmental Factors Affecting Strawberry Quality

The sensory attributes of texture, color, smell, size, and flavor, and the compositional quality attributes of antioxidant and phenolic capacity of strawberries are heavily impacted from pre-harvest factors like genotype and the environment (Gundux and Ozdemir, 2014; Wang and Camp, 2000; Ordidge et al., 2010; Aaby et al., 2012; Tulipani et al., 2008). .

The quality of a berry is affected by environmental factors like sunlight, temperature, exposure, irrigation, and cultivar. These factors play a large role in many aspects of fruit quality. Temperature affects the rate of nutrient uptake and metabolism, strawberry color development, and firmness. Transpiration increases due to temperature increases, thusly increasing nutrient supplies due to high light and temperature (Kader, 1999). Wang and Camp (2000), researched the effect of the differences between day and night temperature and observed that fruit color was darker (L* value decreased) but greater in pigment intensity (chroma value increased) as the difference between day and night temperatures increased. Cooler nights and warmer days resulted in a deeper red berry. Wang and Camp (2000) also observed that soluble solids (SSC), titratable acids (TA), fruit quality, and fruit size decreased with increasing outside temperatures. The change in exposure to daylight and temperature can affect antioxidant properties and sugar content, because of the effect on the maturation process (Gunduz and Ozdemir, 2014; Wang and Camp, 2000; Ordidge et al., 2010). Therefore, light association with high temperature is indirectly responsible for plant metabolism, nutrient uptake, color, and flavor (Kader, 1999;

Wang and Camp, 2000; Sistrunk and Morris, 1985). Inadequate light intensity reduces ascorbic acid, pH, color, and soluble solids (Sistrunk and Morris, 1985). The antioxidant composition of strawberries varies throughout growth and maturity; oftentimes, anthocyanin accumulation occurs in red-colored fruits, with less in the less-mature pink and green fruits (Wang and Lin, 2000; Tulipani, et al., 2011; Kosar et al., 2004). Wang et al., (1996) also observed that darker fruit skin color largely contributes to overall antioxidant capacity. Cultivar selection can affect polyphenolic content in the anthocyanin profile, as well as ripening and growing conditions (Aaby et al., 2012; Tulipani et al., 2008). Wang et al. (2002) researched plasticulture methods with raised beds and subsurface drip-irrigation in comparison to the traditional matted-row method, and found that higher absorbance capacity (ORAC), phenolic acid, flavonol, anthocyanin, soluble solids, and acidity contents existed with fruit grown with the plasticulture method. Gunduz and Ozdemir (2014) also found that the specific growing conditions (e.g. open-field, high tunnel, greenhouse) affected the total phenolic content and soluble solids. They observed no significant differences between the high tunnel and open field system in regards to total phenolic content and soluble solids, but determined that both growing conditions produced fruit with greater amounts of total phenolic content and soluble solids in comparison to greenhouse operations.

Strawberry Production

Fresh strawberry production in the U.S. is a $2.6 billion industry nationwide, with the majority of strawberries grown in California and consumed fresh (~80%) (Demchak, 2009; USDA-NASS, 2015). The U.S. per capita consumption of fresh strawberries was 7.9 lbs/person in 2013 and was forecasted to continue increasing (Perez and Plattner, 2014). Total farms producing strawberries increased 54% and production acreage increased 67% from the 2007 to 2012 census of agriculture (USDA-NASS, 2012).

Kansas has over 65,000 farms statewide and the farms in Johnson County, KS average 174 acres, which are considered small to medium sized and conducive towards intensive agriculture practices (ISPR, 2013). Farms in Johnson County, KS are averaging $28,200 annually. Intensive production of high value crops is suitable for local niche markets. Growers in Kansas are expanding their operations to supply the demand for locally- and regionally-produced strawberries in the Midwest (Demchak et al., 2010). Darby et al. (2008) showed that Midwesterners are likely to pay twice the amount for locally grown strawberries through a direct market versus the supermarket ($0.92 versus $0.48 per basket).

Historically, strawberries in the central U.S. were perennial (3-5 year) “matted-row” systems, used for pick-your-own (PYO) operations. Crops that are well-suited for PYO operations include those with high labor requirements per acre, yet require little expertise to harvest (e.g. berries) (Heidenreich et al., 2007; Ellis et al., 2006; Demchak, 2010). Typically, the strawberries that are grown in the central United States are fall-planted, June-bearing berries that are produced in an annual production system (Juaron and Klein, 2011). The harvest season of the June-bearing cultivars is approximately 6 weeks long (May to mid-June), and harvest coincides with peak national production. June-bearing cultivars are typically seen in the Midwest open-field operations, in order to have maximum production before the extreme summer temperatures.

High Tunnel Production Systems

High tunnels (HT) are unheated greenhouses that can help commercial farmers extend their growing season and increase productivity. Commercial high tunnel production has increased rapidly in recent years due to demand for local produce and studies have shown enhancement of produce quality of the extended growing seasons (Carey et al., 2009). High tunnels are simple, low-cost structures that provide greater control of water application to reduce the risk of disease by protecting crops from rainfall and ambient moisture. Plant growth rates and production are increased by providing even light distribution and increased heat retention to minimize plant stress. The high tunnels rely primarily on passive solar heating and passive ventilation, requiring proper ventilation to trap heat in the cold months and encourage air circulation in the hot months. High tunnel cultivars may be different from open-field cultivars as they are chosen to thrive in higher temperatures and relative humidity (Grubinger, 2012). A survey at the Great Plains Growers Conference (2015) (n=265), showed the 82% of participating growers had already adopted high tunnel operations or (18%) planned to adopt the system due to the success in yield and postharvest quality (Rivard, 2014). A different survey was conducted amongst 81 growers managing 185 high tunnels across Missouri, Kansas, and Nebraska to assess the crops commonly grown, and the areas for future research involving high tunnel production. Tomato was the most commonly grown crop, with the greatest yields from plants grown in the center of the tunnels. Sometimes, HT tomato production was combined with shorter strawberry or leafy green plants grown along the edges of the tunnel (Knewtson et al., 2010). Many state research and extension teams, including Kansas', spoke of plans for small fruit research within high tunnels in response to the demand for locally grown produce (Carey et al., 2009). Generally, states that experience below freezing conditions in the winter will opt for three-season high tunnels which are disassembled before winter to prevent snow accumulation.

Season extension can greatly benefit growers in the early and late season when premium prices are paid for berries (Heidenreich et al., 2007, Rowley et al., 2011; Black et al., 2010). High tunnels add to the productivity of the crop when utilized for protection from wind, birds, and harsh weather, while minimizing disease pressure with less moisture on foliage (Phelps, 2014). Kadir et al. (2006a) observed success with June-bearing strawberries grown in Kansas high tunnels in regards to yield, plant growth, and fruit quality. The high tunnel production method incorporated black plastic mulch, and raised beds. Plants produced berries 5 weeks earlier than the open-field counterparts with 41-54°F warmer soil conditions. Size of berry, soluble solids content, yields, branch-crown development, and plant vigor were greater within the tunnel (Kadir et al., 2006a).

One obstacle with a high tunnel investment is the initial expense and assembly. Three-season high tunnels are disassembled before winter to prevent snow accumulation and cost anywhere between \$0.75-\$1.25/ft^2 whereas four-season high tunnels typically cost \$2-\$3/ft^2 (Blomgren and Frisch, 2007). However, the added income from greater yield and quality is observed to accumulate by year 1 or 2. High tunnels are temporary structures lacking concrete foundations and can be reassembled with relative ease (Blomgren and Frisch, 2007). Typically, there is no supplemental heat source in a high tunnel when night-time temperatures drop below freezing. However, plasticulture production, low tunnels and alternative row covers provides extra insulation sometimes necessary to keep plants alive in the early spring (Hunter et al., 2012).

Strawberry Production in High Tunnels

Day-neutral cultivars are typically produced annually and insensitive to photoperiod so they will continue to grow and produce fruit as long as temperatures are between 40-85°F. Whereas June-bearing cultivar harvest coincides with peak national production (May-June) and depressed wholesale prices (Rowley et al., 2011). In a perennial production system, yield irregularity within the high tunnels is common, winter maintenance is required, and pest problems increase throughout the second growing season (Pritts and Dale, 1989; Hoover et al., 2016). A strong day-neutral cultivar tends to have a moderate number of crowns producing small leaves with less dense canopies; the proportion of dry matter in the root system is one-third that of June-bearers, but the dry matter to fruit ratio is considerably greater (Pritts and Dale, 1989). Day-neutral strawberry cultivars bloom and fruit repeatedly in flushes throughout spring, summer, and fall. Although growers must consider high summer temperatures, which can negatively affect pollination and/or stop flowering. Flushes of day-neutral cultivars are highest in the fall, with lower yields in late July to early August. It is possible that extending the harvest season with day-neutral plants will result in yields ~0.75-1.25 lbs/plant. (Demchak et al., 2010). A successful growing season for June-bearing cultivars would be production of approximately 1.00 lbs/plant (Lantz et al., 2010b). University of Minnesota researchers organically managed six day-neutral cultivars in 2013 and 2014 under straw mulch, plastic mulch, and plastic mulch with low tunnel cultural practices. Total phenolic content and total soluble solid content of fruit was used as an indicator of fruit quality throughout the production season. They found that the day-neutral plants yield greater fruit quantity and had higher total soluble solids content than June-bearing cultivars (i.e. 12.24°Brix in low tunnels for day-neutrals compared to 7.6°Brix for the June-bearing trial under the same growing conditions) (Petran et al., 2016). In regards to production systems, a study in Florida with June-bearing cultivars found that strawberries grown within high tunnels had 7.5% greater soluble solids content than those grown in the open-field system (Donoso, 2009).

A study conducted at the University of Kentucky assessed the yield and cost differences between matted row bare ground, raised bed plasticulture, and high tunnel raised bed plasticulture growing systems with day-neutral production. The two systems using plasticulture, both the raised bed and high tunnel raised bed, displayed strong yield for Midwest strawberry production (~550 qt/2400ft^2) (Fenton, 2010). A second study in high-elevation Utah, successfully maintained successful strawberry production into December as they studied the effect of high tunnels versus low tunnels within high tunnels for day-neutral strawberry production. There was slight increase in yield within the low tunnel + high tunnel system as it provided more hours of optimal growing conditions for strawberry plants in colder months. However, they determined the management of the low tunnel + high tunnel day-neutral cultivars proved difficult and recommend solely high tunnel production for low costs and minimal labor (Rowley et al., 2011).

Growing spring-planted, day-neutral strawberry cultivars in high tunnels could extend the production season, beginning in early June and extending to November. In assessing risk and crop insurance, Belasco et al. (2012) reported that extending the marketing season for strawberries to November and December in areas of Washington, Tennessee and Texas will result in high price premiums. In assessing marketability by production month and indexed monthly prices for strawberries from USDA's National Agricultural Statistics Service (NASS), the average price under the high-tunnel system is 22.9 percent higher than the average open-field operation. Their experiment suggests that high tunnels can mitigate yield shortfalls in addition to increasing yields in years of more moderate weather.

Temperatures greater than 85°F have been observed to reduce berry size and fruit weight (Kumakura and Shishido, 1994) and overall plant growth (Hellman and Travis, 1988). Flower initiation, development, firmness, sugar content, and aromatics is also inhibited with temperatures over 85°F (Lantz et al., 2010b). The extreme temperatures reached during the summer months in Kansas deter farmers from growing high-value strawberry crops, because of the negative impact on yield and fruit quality. Shade cloth and evaporative cooling are techniques that could be used to overcome this problem. Rowley et al. (2011) studied high tunnel production and the effectiveness of shade cloth at reducing drought/heat stress to increase yields of day-neutral cultivars in Utah. Studies show that high tunnels can increase temperatures as much at 39°F in winter months, and replacing the plastic roofing with 40% shade cloth during high temperature months can decrease the temperature by 39°F. Phelps (2014) suggests proper ventilation to increase air circulation, and overhead misters to decrease plant temperatures. Tarnished Plant Bug (*Lygus lineolaris*) is damaging to day-neutral cultivars because the strawberries flower during high summer temperatures at the same time the pest is most active and numerous. Regular scouting and high tunnel plant rotation is necessary to manage any population presence (Hoover et al., 2016). In addition, the aphid, a common strawberry pest, thrives in high tunnels and requires vigilant management (Phelps, 2014). With appropriate management, growing day-neutral strawberry cultivars under high tunnels could be feasible in the central U.S.

Evaporative Cooling in Fruit Production

Evaporative cooling is a novel technique that could be used to overcome the problem of high internal plant temperature (Lantz et al., 2010b; Koike et al., 2009). Heat energy from the plant converts the liquid water into gas through the exothermic process. The energy from the plant is absorbed by the overhead water which cools the plant (Thompson, 2002). Application of evaporative cooling (i.e. hydrocooling) pre-harvest is potentially impactful for pest and disease control (Dara, 2012), fruit maturity, fruit storage characteristics, fruit color development (Parchomchuk and Meheriuk, 1996; Van Den Dool, 2006; Lantz et al., 2010a; Koike et al., 2009). Typically used amongst produce growers are evaporative cooling systems with above-plant misters or sprinklers. Depending on the produce species and genotype, evaporative cooling has shown to enhance yield weights, redness color, and storage life quality in grapes and apple production (Parchomchuk and Meheriuk, 1996; Evans, 2004; Aljibury et al., 1975).

Parchomchuk and Meheriuk (1996) found the use of evaporative cooling for 'Jonagold' apples reduced soluble solid concentration and increased titratable acidity and storage times but did not affect fruit size, firmness, or redness. They deduced that fruit redness is improved with cooler internal temperatures. However, specific cultivar and/or climate selection will differ in its response to evaporative cooling. Evaporative cooling is utilized in orchards to cool tree fruit through evapotranspiration and prevent sunscald. Apple and pear orchardists use evaporative cooling for 35 – 75 days or more per season when temperatures over 32°C (Van Den Dool, 2006; Evans, 2004). Evaporative Cooling is inefficient in its requirement of large amounts of water. Therefore, current research is proposing management criteria for effective evaporative cooling system that develops a physical model to predict skin temperatures of fruit exposed to direct sun during cooling, and the rate at which water must be applied to reduce the fruit temperature. Evans (2004) constructed a cooling system based on the theory, "If the amount of heat extracted is greater than the total incoming heat energy, then the temperature of the fruit will decrease." He created a model based on temperature and wind patterns to determine the proper application rate and water amount to efficiently maintain the targeted fruit temperature. Its use has been widely suggested as a potential application in strawberry and small fruit production in U.S. regions to reduce the high heat potential in high tunnels (Lantz et al., 2010a; Roos and Jones, 2012; Johnson, 2011), however no known research has occurred to reduce strawberry temperature within high tunnels.

Evaporative Cooling with Strawberry Production

During the heavy bloom period, overhead evaporative cooling of the blossoms may benefit the heat tolerance of the plants. Growers have deduced that evaporative cooling can improve color by reducing incidence of type III bronzing damage in strawberries, due to heat stress (Koike et al., 2009). Past research on evaporative cooling, within the realm of plasticulture high tunnel systems is minimal to none. Willie Lantz (2010a) from Penn State, worked with day-neutral strawberry cultivars in high tunnels in the north-eastern region on the U.S., and suggested involving evaporative cooling as a possible future alternative for growing strawberries in warmer summer climates. However, extension specialists, Lantz et al. (2010a), suggests that this system may show more benefits during plant establishment than plant production, to reduce foliar moisture. Phelps (2014) notes that disease pressure from *Botrytis cinerea*, a popular fungal plant pathogen of strawberry, may benefit from the added humidity in the high tunnel if it is not properly ventilated. The system's ability to augment fungal pressure will help determine the utility of evaporative cooling inside the shaded high tunnel.

Strawberry Postharvest Physiology

Strawberries are one of the most perishable fresh fruit crops. They are a non-climacteric fruit, meaning that they cannot ripen off the plan; they must be harvested fully ripe to obtain superior organoleptic quality (Becker and Fricke, 1996). Typical time from anthesis to harvest is 30-40 days, when environmental influences fruit quality (Symons et al., 2012). Strawberries have a high respiration rate (about 15 mg CO_2/Kg-h at 32°F) and increase 4- to 5-fold when temperature is elevated to 50°F (Kader, 1991). Strawberries produce very low (less than 0.1 ul/Kg/h) levels of ethylene. It has been reported that ethylene does not play an essential role in the regulation of ripening in strawberries and auxin may be the main hormone controlling ripening. Kader et al. (2006b) suggests that variability amongst cultivar may tolerate heat exposure at different temperatures. Strawberry hormone levels are based on the genotype which has shown to determine postharvest quality aspects. Hormone levels of absicic acid (ABA) begin rising two weeks prior to harvest after the fruits change from green-to-white (Symons et al., 2012). The increase in ABA levels observed during fruit development coincides with the onset on color (Symons et al., 2012), and has been reported to increase anthocyanin levels (Jia et al., 2011), and stimulate sucrose in in-vitro applications (Archbold, 1988).

Temperature affects the rate of nutrient uptake and metabolism, strawberry color development, and firmness. Transpiration increases due to temperature increases, therefore increasing nutrient supplies due to high light and optimal temperature (Kader, 1999). Good temperature management after harvest, including rapid cooling postharvest and maintaining low pulp temperature is the single most important factor to maintain strawberry quality during storage life (Jin et al., 2011; Kader, 1991). Strawberries stored in low temperatures around 32-36°F and a relative humidity of 95% to prevent moisture loss, resulting in higher water content within the cell walls (Harris, 2007). The optimum storage period for strawberries stored in optimum temperature is 7 days (Harris and Mitcham, 2007). The turgidity from the high water content increases berry firmness, and firmness affects the susceptibility of the berry to physical damage (Kader, 1991; Szczesniak and Smith, 1969). Storage temperature is responsible for the stability of phenolic antioxidants in fruits during postharvest storage (Olsson et al., 2004; Tulipani, et al., 2010). Total phenolic and antioxidant capacity either increases accumulation or remains the same throughout storage even when taste and smell deteriorate, due to defense reactions taking place (Ayala-Zavala et al., 2004). Soluble solid content is positively correlated to water content (i.e. weight loss). Hernández-Munoz et al. (2008) found as strawberries begin to lose moisture content, the sugar becomes more concentrated, thus increasing soluble solid content.

The anthocyanin concentration is also important for postharvest quality of fruit; in addition to its nutritional capacity, it is responsible for the bright red flesh. Anthocyanin content largely constitutes the antioxidant content in most berry species and typically resides in the skin (Prior et al., 1998).This coincides with Bakker et al. (2004) who observed that strawberry color stability depends on anthocyanin content of individual cultivars. Antioxidant properties help defend against external stresses. In plant organs, oxidative stress is involved in ripening and degradation, by delaying plant senescence as a plant defense (Brennan and Frenkel, 1977). A study conducted to understand the stress response of the antioxidant properties in blueberries, raspberries, and strawberries found that antioxidant concentration remains stable at temperatures near 0°C postharvest, with increased antioxidant concentration in strawberries stored at 5°C or 10°C (Kalt et al., 1999; Ayala-Zavala et al., 2004). Kalt et al. (1999) suggests that storage at ambient temperatures can have a positive effect on the phenolic metabolism to enhance antioxidant capacity. However, it was noted that the taste and smell deteriorate due to increased aroma volatiles at ambient temperatures, which compromised acceptable overall quality for long storage duration (Ayala-Zavala et al., 2004; Piljac-Zegarac and Samec, 2011). However, Hernández-Herrero and Frutos (2014) researched storage effects on natural strawberry extract, and observed that antioxidant capacity in strawberries degrades over time and has a relatively low stability over long periods of storage time (0-8 weeks) at storage temperatures over 16°C.

Research Objectives

Local strawberry production in the Midwest is increasing yearly. However, the harvest season is limited with fall-planted June-bearing from May-mid-June. Season extension techniques like growing in high tunnels could increase crop availability, but fall-planted crops occupy winter production space. Day-neutral cultivars could be successful when planted in the spring in Kansas and throughout the central U.S. With intensive management and cultural practices, the production season could extend from May-November, providing growers with late-season prices in the fall, when the highest prices are paid for strawberries. Evaporative Cooling could reduce heat stress for plants grown within the high tunnel and promote evaporation and internal cooling of the berries in order to produce high quality fruit. With the dramatic increase of high tunnel utilization in the Midwest for specialty crops, the implementation of spring-planted strawberry production in the high tunnel could increase profitability, while providing a high-value crop to rotate from tomatoes. However, there are no reports of the specific day-neutral strawberries cultivars within a high tunnel that are successful in the central U.S. Similarly, little is known about the impact of utilizing an overhead evaporative cooling system during hot summer days, and the effects that it may have on yield and fruit quality. In order to address some of the questions that were raised above our research objectives were the following:

1. Investigate the feasibility of spring-planted, day-neutral cultivars in a high tunnel production system in Kansas,
2. Identify spring-planted day-neutral cultivars that are successful in a high tunnel system in Kansas and the utility of evaporative cooling, in regards to yield and marketability throughout the production season,
3. Determine at harvest and postharvest quality of the spring-planted day-neutral cultivars that perform optimally in a high tunnel production systems and the utility of evaporative cooling.

Chapter 2 - Spring-Planted Day-Neutral Strawberries for High Tunnel Production in the Central U.S.

Abstract

Intensive specialty crop production within high tunnel systems in the Central United States has greatly expanded. This production system, along with spring-planted day-neutral strawberry production, could provide growers with both early and late-season income by season extension and enhanced postharvest quality. This study identifies which spring-planted, day-neutral strawberry cultivars are successful in a plasticulture, high tunnel system in regards to yield and marketability and investigates the effect of evaporative cooling. The trial was conducted at the Kansas State University Olathe Horticulture Research and Extension Center during summer 2014. Six commercially available cultivars were evaluated (‘Albion’, ‘Evie 2’, ‘Monterey’, ‘Portola’, ‘San Andreas’, and ‘Seascape’). Mature fruit (90-100% red), was harvested twice weekly for total and marketable yield (weight, number and size), in addition to marketability (weight and number). Our results indicate that throughout the entire season (10 May 2014-6 Oct. 2014, and 31 May 2015- to 6 Oct. 2015), ‘Portola’ had the highest yields in 2014 and 2015 at 1.33 lbs/plant and 1.12 lbs/plant, respectively. In 2014, ‘Portola’, ‘Evie 2’, and ‘Seascape’ produced high yields in comparison to the other cultivars ($P < 0.0001$); in 2015, ‘Portola’ and ‘Evie 2’ produced high yields in comparison to the other cultivars ($P < 0.001$). Fruit size of ‘Seascape’ was small in comparison to ‘Portola’ in both production years ($P < 0.0001$). Marketability was high among all cultivars with the highest marketability seen with ‘Albion’ and ‘Monterey’ in 2014 and 2015 in comparison to ‘Evie 2’ ($P < 0.01$). Throughout the season, fruit yield was highest in mid-season while fruit size was largest in early season among all cultivars.

In our trials, evaporative cooling did not affect yield or the incidence of disease. This production system in Kansas has the potential for success based on production yield of the fruit seen in our study.

Introduction

High tunnels are unheated, polyethylene film-covered greenhouse structures used around the world to reduce limitations of harsh weather and temperature fluctuation (Lamont, 2009; Wells and Loy, 1993). High tunnels provide season extension for farmers who grow high value crops, such as strawberries (*Fragaria x ananassa*) (Black et al., 2010). In Kansas, high tunnel strawberry production has begun five weeks prior to open-field production (Kadir et al., 2006a) This system reduces leaf wetness from excess moisture, *Botrytis cinerea* and pest damage, while increasing the air temperature, to improve marketability (Heidenreich et al., 2007; Santos et al., 2010). High tunnel production of strawberries has potential for early fruit production due to protected crowns during winter months and extension outside the typical production season in Kansas. A study comparing open-field versus high tunnel systems, found that high tunnel production resulted in larger fruit, larger leaf area, greater leaves and shoot biomass, and fewer runners (Kadir et al., 2006a). In Kansas, Knewston et al. (2012) found high tunnel June-bearing plant production to arrive 5 weeks prior to open-field production. High tunnels can substantially improve marketable yields, shelf life, and extend the marketing season for strawberries (Kadir and Carey, 2004; Santos et al., 2010; Belasco et al., 2012). However, high tunnels require careful management to prevent excessive temperatures and humidity inside the structure in the warmest months (Galinato and Walters, 2012).

Production temperatures, together with the genotype, and irrigation, are the most important parameters that regulate crown development and consequently, berry size (Wang and

Camp, 2000; Hortynski et al., 1991; Connor et al., 2002; Poling, 2012). It has been reported that production temperature is another major factor that can affect berry size within strawberry production, which tends to decrease with temperatures above 85°F (Wang and Camp, 2000; Kumakura and Shishido, 1994; Poling, 2012). That is because ideal crown development (between 3 to 6) occurs at temperatures around 55-85°F, which encourages high yields with large fruit size. High temperatures above 85°F encourage crown development (>6) which will potentially decrease fruit size (Poling, 2012). Kadir et al. (2006a) observed that June-bearing strawberry production within a high tunnel system in Kansas resulted in greater berry size in comparison to open field when harvested in May to June. They also found positive correlations between number of fruit, average fruit weight, and largest fruit weight within the high tunnel production system. However, June-bearing plants are fall-planted and spring-harvested for approximately 6 weeks long (May to mid-June). This requires winter crop room for a harvest that coincides with peak national production, in order to have maximum production before the extreme summer temperatures.

Kansas summer months of late-June to early August often experience temperatures above 85°F (Kansas Mesonet, 2014). A solution to this challenge in high tunnels is shade cloth and proper ventilation. Evaporative cooling is a novel solution that could be used to overcome the problem of high strawberry plant temperature. As outside air passes through the plant canopy, the plant cools through evaporation. Heat energy from the plant converts the liquid water into gas through the exothermic process. The energy from the plant is absorbed by the overhead water, which cools the plant (Thompson, 2002). Several extension specialists suggest it as a method to decrease plant internal temperature and increase yields or postharvest quality (Lantz et al., 2010a; Koike et al., 2009; Roos and Jones, 2012; Johnson, 2011); however, the common practice is with strawberry propagation or during plant initiation (Poling, 2014). In California, this system has been studied in commercial production during plant establishment before flowering, or in the open-field plasticulture system under direct sunlight to enhance yield, and plant health by enhancing the plants microclimate (Dara, 2016). However, Dara (2016) found a reduction of salt injury, mite infestation, and *Botrytis cinerea* with no indication of yield or internal temperature changes with the use of the micro-sprinklers. Typically used amongst produce growers in orchard production and some commercial berry applications are evaporative cooling systems with above-plant misters or sprinklers (Parchomchuk and Meheriuk, 1996; Evans, 2004). In California, vineyards have adopted the strategy of overhead sprinklers with temperatures over 90°F to cool the fruit temperature. They observed positive results from in regards to yield, while also delaying fruit maturity (Aljibury et al., 1975). In apple production, evaporative cooling enhances color and storage life quality depending on the produce species and genotype (Parchomchuk and Meheriuk, 1996; Evans, 2004).

Traditionally, in the central U.S., June-bearing cultivars are used for strawberry production due to their successful, short, six-week, high-yielding harvest period (Kadir et al., 2006a; Demchak, 2010). However, yields of day-neutral cultivars are typically higher than those of June bearers because of the extended harvest season (Demchak et al., 2010; Pollack and Perez, 2008; Rowley et al., 2011). In the high elevation region of Utah with hot summer temperatures (above 85°F), Rowley et al., (2011) found peak high tunnel June-bearing production to arrive 4 weeks prior to peak high tunnel day-neutral production. High tunnel day-neutral strawberry production extended from late-May to mid-December, with total yields greater than the high tunnel June-bearers. Yields of 0.75 to 1.25 lbs/plant are reasonable for strawberries in high tunnels in Pennsylvania (Demchak et al., 2010). Growing spring-planted, day-neutral strawberry cultivars in a high tunnel system could be a production alternative to ensure growers with late-season prices. This still allows them to rotate fall and winter crops into the system (Heindenreich et al., 2007, Rowley et al., 2011; Pollack and Perez, 2008). In contrast, June bearing cultivars come with a high opportunity cost when grown in high tunnels as they are typically planted in fall and eliminate winter production space in the high tunnel (Santos et al., 2010). Harvesting for day-neutral cultivars occurs in the late spring and until mid-fall. Not taking into account the initial cost of a high tunnel, Lantz et al. (2010b) gauged feasibility in the local northeastern U.S. market through an economic study. Considering the ease of harvesting within the high tunnel and supply costs, the grower will have high profits during the 15-20 week harvest period, if the day-neutral berries sell for $2.00-$4.00/lbs. premium prices for strawberries occur in October and November, when production is lowest on a national scale (Belasco et al., 2006). Because the prices are better outside of the peak local season, growers adopting this production system could sell produce a month later than the competitor and benefit from the late-season prices because of the 15-20 week production cycle. Strawberry production in high tunnels in Kansas could be a profitable solution for specialty crop growers. However, the high summer temperatures may negatively affect yield and fruit quality. The objectives of this study were to investigate the feasibility of spring-planted, day-neutral cultivars in a high tunnel production system in Kansas. And to identify spring-planted day-neutral cultivars that are successful in a high tunnel system in Kansas and the utility of evaporative cooling, in regards to yield and marketability throughout the production season.

Materials and Methods

Experimental Plan and Plant Material

The experiment was conducted at the Kansas State University Olathe Horticulture Research and Extension Center (OHREC) during the 2014 and 2015 growing seasons. OHREC is located in Johnson County, Kansas. The land has chase silt loam (pH 6.5). The trial, located within a three-season high tunnel (200’ x 24’) (Haygrove Inc., Mount Joy, PA) with 30% shade cloth, applied once daytime temperatures were consistently around 85°F. In 2014 and 2015 this was late-June. The crop utilized drip irrigation and black plastic mulch for weed control. The experiment was arranged in a split-plot design with four replications (Fig.1). The main plots included the use of evaporative cooling (with and without) and the subplots consisted of the six cultivars that were randomly assigned to the subplots. Six cultivars of day-neutral strawberry (*Fragaria x ananassa* Duchesne ex Rozier) were selected as popular commercial standards, including ‘Evie 2’ (Edward Vinson Breeders in Kent, England), ‘Albion’, ‘Monterey’, ‘Portola’, ‘San Andreas’, and ‘Seascape’ (all from University of California at Davis). In both production seasons, the trial included four rows with twelve plots per row (48 plots total), and twenty plants in each plot. Each plot (10’ in length) had 5’ spacing between rows and 12” in-row spacing. The experimental design remained the same between production seasons 2014 and 2015, with spacing in between main plots to reduce interplot interference.

Plant spacing and cultural methods were consistent with strawberry production in the region. Weeds were suppressed via woven fabric mulch and plastic mulch and runners were removed on a weekly basis. In 2014, pre-plant fertilizer included 40lbs N/acre and 60lbs K/acre from a combination of Calcium Nitrate $Ca(NO_3)_2$ and Potassium Nitrate KNO_3; in 2015, an increased 60lbs N/acre and 120lbs K/acre, in addition to 120lbs PO3-4/acre and 12lbs Mg/acre. The trials were planted on 7 Apr. 2014 and 23 Apr. 2015. Ten applications of nitrogen (10 lbs/acre) were applied throughout 2014, from 18 Apr. 2014 to 7 Aug. 2014, and six applications applied throughout 2015, from 17 Apr. 2015 to 17 Aug. 2015. Strawberries were sourced as bare root plants from Nourse Nursery in Massachusetts. Due to late-winter frost conditions in Massachusetts, strawberries were planted with a two-week delay in 2015. Plant spacing and cultural methods were consistent with strawberry production in the region.

Evaporative Cooling

Evaporative cooling (EC) was applied once air temperature was consistently reached 85°F by 12:00pm. 5-8 minute application were applied at 12:00pm or until drip point. In 2014, evaporative cooling was applied from 24 June 2014 to 14 August 2014, with 30 days throughout this period reaching over 85°F. In 2015, application began 13 July 2015 until 8 Sept. 2015, with 38 days throughout this period reaching temperatures over 85°F. However, days with EC use was not consistently recorded throughout the growing seasons. A 1000-gallon clear plastic tank was filled with potable-city water and positioned at the north end of the high tunnel (Fig. 2). It was suited with a timer to automatically dispense water for 5 minutes over the canopy of the EC plots or until drip point.

Data Collection

The strawberries were harvested twice weekly at commercial ripeness (90-100% red), then sorted and graded as marketable or non-marketable and recorded. Non-marketable fruit were determined based upon the presence of decay, gray mold, and small size (larger than 3cm diameter to include in total yield), and/or pest damage. At the end of each growing season, the plants were stripped of all fruit larger than 3cm (including green or white). In 2014, strawberries were harvested from 10 May 2014 to 6 Oct. 2014. In 2015, strawberries were harvested from 31 may 2015 to 6 Oct. 2015.

Marketability was determined as a percent of the total yield and were calculated based on fruit weight and fruit number. Average fruit size was determined in ounces as a measurement of strawberry fruit count within the total yield. The effects of EC on yield and marketability is determined from the dates that the system was turned on until the end of the growing year. Individual fruit with any presence of gray mold *Botrytis cineria* were harvested and the yield number (incidence/plant) was recorded separately to determine the pre-harvest decay as a result of added moisture on the plant canopy from the use of EC. In 2014, incidence of gray mold was measured seven times as a method of examining the effect of evaporative cooling on excess canopy moisture. In 2015, incidence of gray mold was measured twenty times.

During the two growing seasons, we identified three distinct periods related with peak times of fruit growth. Examining the yield differences between early-season, mid-season, and late-season helps develop this system further by understanding the fruit flushes throughout the sixth month period. Early season coincided with national peak production and peak local season for June-bearing cultivars. Mid-season occurred during the hottest daytime temperature months and throughout the evaporative cooling applications. Late season production was determined through lower temperatures as the season moved into early fall. In 2014, the early season harvest was from 10 May 2014- 31 June 2014, mid-season was from 1 July 2014- 14 Aug. 2014, and late season was from 15 Aug. 2014- 6 Oct. 2014 (Fig. 3). In 2015, the early season harvest was from 31 May 2015-31 June 2015, mid-season was from 1 July 2015-14 Aug. 2015, and late season was from 15 Aug. 2015- 6 Oct. 2015 (Fig. 4). These dates were determined by examining the cultivar flushes. Distinct peaks in production fell between these dates of both production year. In addition, we wanted similar harvest intervals within each segment which allows for approximately seven to eight weeks for early, mid-, and late season production in 2014, with a shorter four week early season production in 2015 due to later planting dates.

Statistics

The harvests from each year were evaluated for yield and marketability and averaged for the purpose of this paper. To evaluate significant ($P < 0.05$) differences between cultivars, treatments, and years, analysis of variance (ANOVA) was performed to determine which factors and interaction between factors affected the total and marketable yield as well as the marketability of strawberries. When interactions were found not significant, overall value was used to compare the means of factors. Significant differences between mean cultivar responses, treatment, and year effects were evaluated by using Tukey's multiple comparison test ($P \leq 0.05$). Each value in the Tables is expressed as the mean while the Figures are expressed as mean ± standard deviation. Data in Table 1 was analyzed by SAS System (1998; SAS Institute, Inc., Cary, NC). Data in Table 1-3 and Figures 5-7 were analyzed by JMP Systems (JMP, version 13, SAS Institute Inc., Cary, NC 1989-2007).

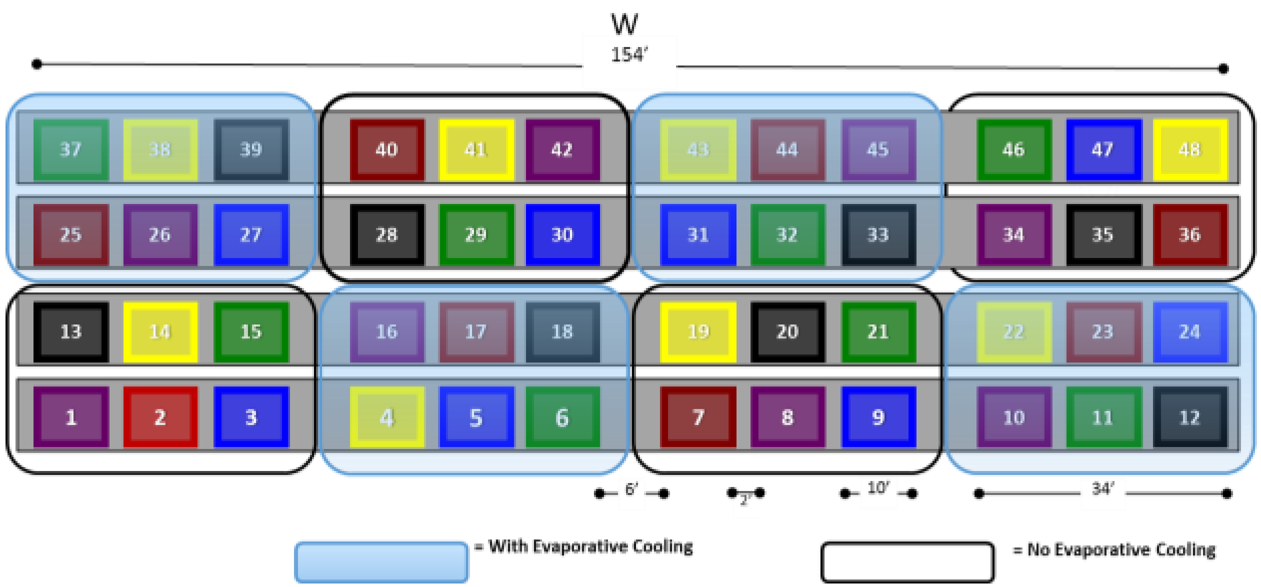


Figure 1- The 2014 plot map experimental design.

The trial consisted of 48 plots (10' length) and designed in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were the cultivars. The trial was located at the Olathe Horticulture Research and Extension Center (OHREC) on four rows in a three season high tunnel with 30% shade cloth.

Figure 2- 1000-gallon tank situated at the north end of the high tunnel that held water for the evaporative cooling applications.

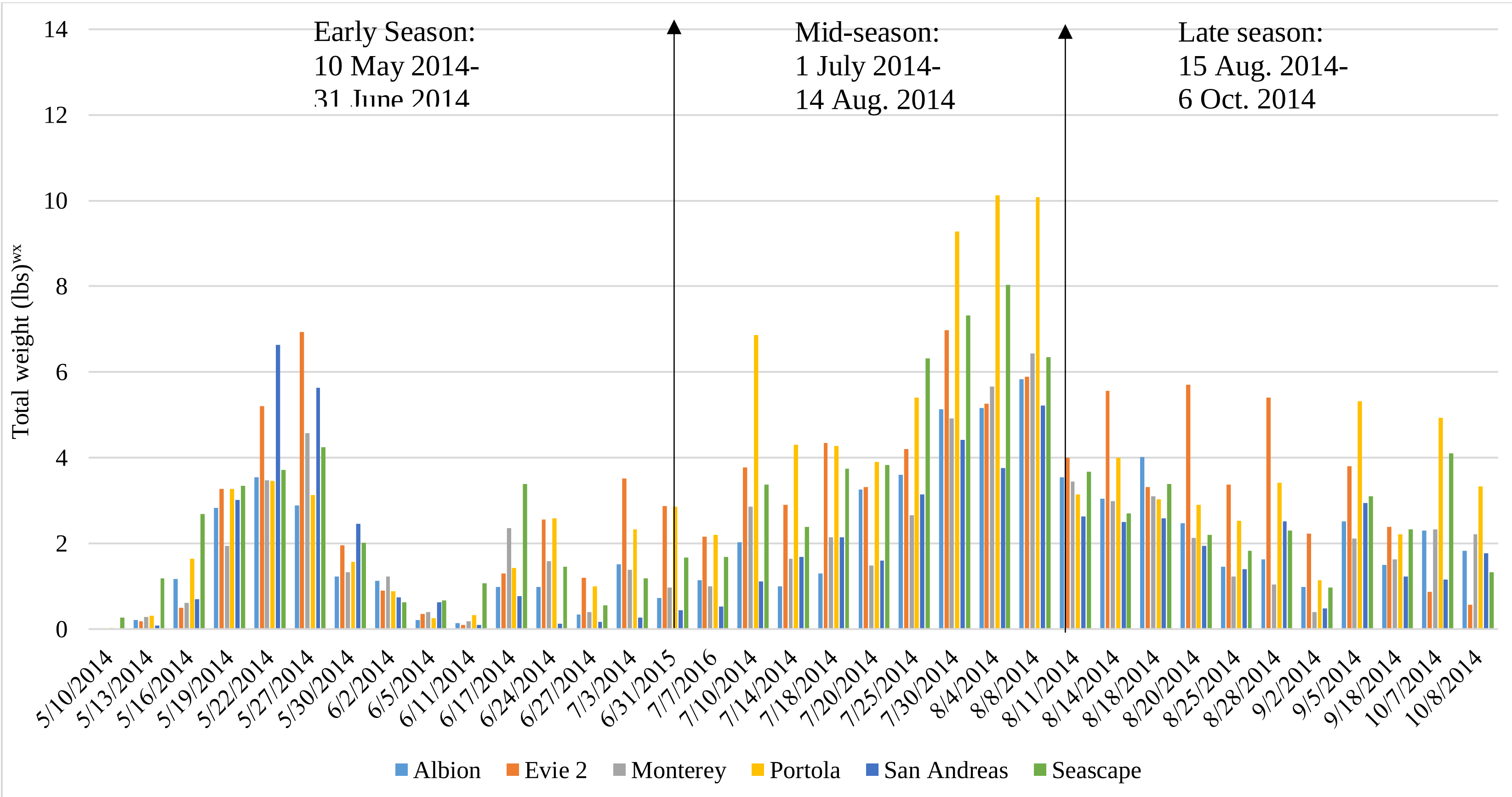


Figure 3- Total weight (lbs) of fruit produced throughout the 2014 production season by the 6 day-neutral cultivars.

Arrows separate the early, mid-, and late season production periods.

[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).

[x]Experimental design as described in fig. 1 at Olathe Horticulture Research and Extension Center in a 3 season high tunnel with 30% shade-cloth in a split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars

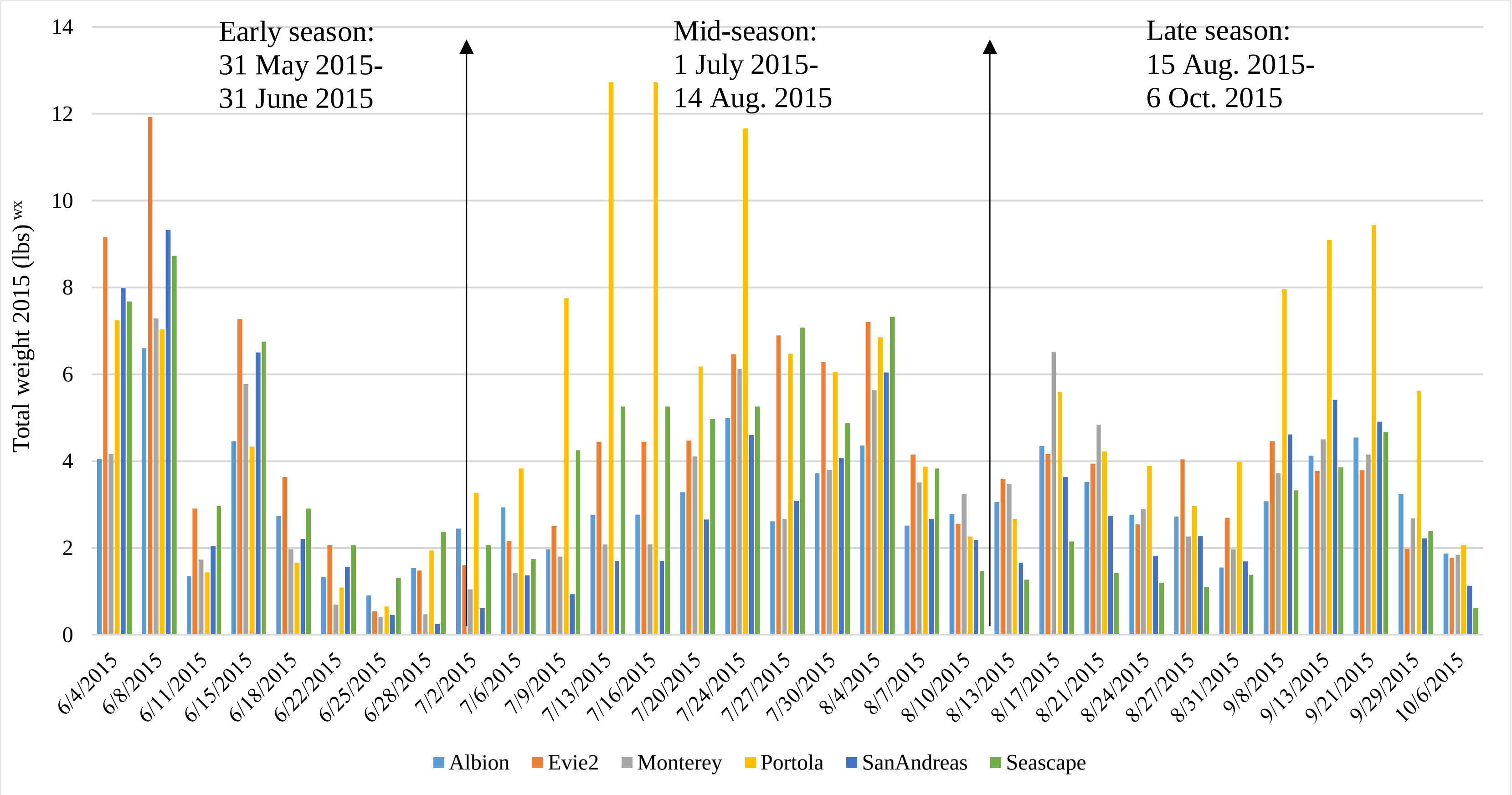


Figure 4- Total weight (lbs) of fruit produced throughout the 2015 production season by the 6 day-neutral cultivars.

Arrows separate the early, mid-, and late season production periods.

[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).

[x]Experimental design as described in fig. 1 at Olathe Horticulture Research and Extension Center in a 3 season high tunnel with 30% shade-cloth in a split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Results

Means of yield for the six strawberry cultivars that were examined are presented by weight (lbs/plant), number (fruit/plant), and size (oz/fruit) and separated by years in Table 1. In 2014 total yield (by weight) was significantly higher than 2015 ($P < 0.001$) with a mean at 1.00 lbs/plant and 0.76 lbs/plant respectively. In 2014, ‘Portola’, ‘Evie 2’, and ‘Seascape’ yielded high weights greater than 1.00 lbs/plant (1.33, 1.16, and 1.05, respectively) compared with the other three cultivars evaluated. ‘Portola’ had significantly greater total weight/plant than ‘Monterey’, ‘Albion’, and ‘San Andreas’ ($P < 0.0001$). The total weight in 2015 was similar to 2014 with ‘Portola’ yielding significantly more fruit at 1.12 lbs/plant than all other cultivars except ‘Evie 2’ where the difference was not significant. In 2015, ‘Portola’ yielded 32.2% greater total weight than the yearly average. The evaporative cooling treatment did not significantly affect the total weight per plant for all cultivars in both years. ‘Portola’ with 56.1 fruit/plant, and ‘Evie 2’ and ‘Seascape’ both with 55.4 fruit/plant had significantly more total number than the other three cultivars in the study ($P < 0.0001$). No significant effect on total weight was seen from the EC.

In 2014, the size of the berries was significantly higher than in 2015 for all cultivars (Table. 1). In 2014, ‘Portola’, ‘San Andreas’, and ‘Albion’ had the largest berries 0.39, 0.39, and 0.37 oz/berry (Table 1). ‘Seascape’ produced smaller berries than all the other cultivars ($P < 0.0001$) 0.29 oz/berry, followed by ‘Evie 2’ 0.31oz/berry. In 2015, ‘Portola’ had significantly higher total fruit size at 0.31 oz/berry followed by ‘San Andreas’ at 0.28 oz/berry compared with the rest of the studied cultivars. Across the two years, ‘Portola’ had significantly higher total weight, number, and fruit size compared with the rest of the studied cultivars. ‘Seascape’ and ‘Evie 2’ also had significantly high total fruit weight and number, but significantly smaller size compared with the rest of the studied cultivars for each across production years ($P < 0.0001$) (Table 1). No significant effect on total fruit size was seen from the EC.

The yield by number (fruit/plant) in Table 1 was not significantly different between growing years. ‘Portola’ with 56.1 fruit/plant, and ‘Evie 2’ and ‘Seascape’ both with 55.4 fruit/plant were greater than the other three cultivars in the study ($P < 0.0001$). The mean by total number were similar across growing year with 46.3 fruit/plant. In 2014, plants grown without evaporative cooling resulted in a greater yield number. Contrastingly, plants grown with EC produced a greater yield number (Table 2).

The marketable number fruit/plant was not significantly different between the two years (Table 1). In 2014, the marketable fruit weight ranged from 0.59 to 1.12 lbs/plant with ‘Portola’ having high ($P < 0.0001$) marketable weight 25% greater than the season mean, and ‘Evie 2’ following with 0.93 lbs/plant. ‘San Andreas’ produced significantly less marketable yield by weight 0.59 lbs/plant. In 2015, strawberries from ‘Portola’ cultivar had significantly greater marketable weight and produced 33.7% greater marketable fruit compared to the season mean. The evaporative cooling did not significantly affect the marketable yield by weight, for all the cultivars tested in both years.

In 2014, ‘Portola’ and ‘San Andreas’ had greater marketable size ($P < 0.0001$) than the rest of the cultivars tested and strawberries from ‘Seascape’ were the smallest in size (Table 1). Similarly, in 2015, ‘Portola’ produced greater marketable sized fruit at 0.33 oz/fruit and ‘Seascape’ strawberries were smaller than the other cultivars at 0.23 oz/fruit. The strawberries treated with evaporative cooling did not have any significant differences for the marketable fruit yield parameters in comparison to those not treated with evaporative cooling.

During 2014, 88.59% of the strawberries harvested from ‘Albion’ were marketable (by weight) ($P < 0.01$) and significantly greater compared to ‘Evie 2’ and ‘San Andreas’ which were significantly lower in percent marketability (by weight) among the cultivars tested (Table 1). In 2015, ‘Monterey’ produced fruit with the highest percentage of marketability (by weight) at 83.48% which was significantly more than the strawberries from ‘Evie 2’ ($P < 0.05$) with the lowest percent marketability among all the cultivars at 76.5%. Production year differences were observed in percent marketability with a significantly higher percentage of marketable fruit (by weight) in 2014 than in 2015, at 80.1% and 74.9%, respectively.

The marketability by fruit number for the cultivars 'Albion', 'Monterey', and 'Seascape' were significantly higher in 2014 (84.4%, 82.2%, 81.4%, respectively) compared to 'Evie 2' and 'San Andreas' which resulted in significantly lower marketability ($P < 0.01$). In 2015, the marketability by number was significantly higher ($P < 0.01$) among 'Albion', 'Portola', and 'Monterey' (78.1%, 77.1%, and 77%, respectively) while 'Evie 2' was significantly lower in marketability by number ($P < 0.01$) (Table 1).

Only fruit mold counts from 2015 are displayed in Table 3. There was very little gray mold incidence within the high tunnel system from the beginning of season harvest (31 May 2015) until the first EC application (13 July 2015). Once the evaporative cooling system began for the production year, there were no observed difference between plots grown with and without EC. The plots with 'Evie 2' produced 3.62 gray mold incidence/plant ($p<0.001$).

In 2014, the early season began at the first harvest 10 May 2014 until 31 June 2014. In 2015, the early season began at first harvest 31 May 2015 until 31 June 2015. Looking closer at the total yield flushes by weight (lbs/plant) throughout the 2014 production year (Fig. 5A), the early season production was similar across growing years and between cultivars, with the exception of 'Albion' which had significantly higher yield in 2014 early season in comparison to the remaining cultivars. Throughout the mid-season (Fig. 5B), we see significant differences of mid-season total yield between production years with peak production in 2014 occurring in mid-season among all cultivars, with the exception of 'San Andreas'. Mid-season 'Portola' in 2014 was the highest yielding cultivar by weight, with significantly greater total yields in comparison to all cultivars across both production years, with the exception of 2014

‘Evie 2’ and ‘Seascape’. In the late season (Fig. 5C), there was no significant difference within cultivars or between production years, although the highest total yields were observed from the 2015 ‘Portola’. Late season yields in 2014 were significantly less among all cultivars in comparison to mid-season yields in 2014, while ‘Seascape’ peaked in mid-season production in both 2014 and 2015. The overall pattern between early, mid-, and late season total yields by weight were similar between production season with the largest differences in the mid-season with the 2014 mid-season mean at 0.517 lbs/plant, and the 2015 mid-season mean at 0.327 lbs/plant.

Total fruit size (oz/fruit) during the seasons (early, mid-, late) are displayed in Fig. 6. There was no significant difference between production years or within cultivars in the early season (Fig. 6A). In mid-season (Fig. 6B), there were no significant differences within the same cultivar or growing years; however, ‘Seascape’ produced a significantly small berry in comparison to ‘Portola’ across both growing years. During the late-season (Fig. 6C), there was no significant differences within the same cultivar or across growing years for total fruit size. The overall pattern between early, mid-, and late season show that early season production results in the largest fruit greater than 0.4 oz/fruit.

The marketability by weight during the seasons (early, mid, late) are displayed in Fig. 7. In the early season (Fig. 7A), and mid-season (Fig. 7B), there was no significant difference between production years or within cultivars. However, in late season (Fig. 7C) ‘Albion’ and ‘Portola’ produced in 2014 had significantly greater marketability than ‘Evie 2’ and ‘Seascape’ produced in 2015. In general, marketability was highest in mid-season with all cultivars throughout both production years averaging $\geq$80% marketability.

Discussion

The feasibility of producing day-neutral spring-planted strawberries in high tunnel production, and the identification of successfully yielding cultivars specific in this system in the central U.S.

throughout the production season, with the utilization of evaporative cooling was assessed in this report. The total and marketable weight differences were similar between years 2014 and 2015 amongst the six chosen day-neutral cultivars. The individual cultivars acted similarly across the two growing years, with no significant change in yield pattern. Our results suggest that ‘Portola, ‘Evie 2’, and ‘Seascape’ were the highest yielding cultivars by weight in 2014, while ‘Portola’ and ‘Evie 2’ were the most successful cultivars in terms of fruit yield in 2015. In 2014 alone, every cultivar (with the exception of the low yielding ‘San Andreas’ fell within the desired range of total yield reported 0.75-1.25 lbs/plant for day-neutral cultivars within a high tunnel (Demchak, 2009). In 2015, only ‘Portola’ and ‘Evie 2’ fell within the desired range of total yield by weight (lbs/plant). A study done in high altitude climate of South Korea by Ruan et al. (2013a) observed the yield and quality parameters between and among June-bearing and day-neutral cultivars in high tunnels- ‘Albion’, ‘Monterey’, ‘Portola’, and ‘San Andreas’. Their marketable yield by weight averages for day-neutral cultivars were 0.7 lbs/plant. In our study, the average day-neutral plant produced marketable yields of 0.84 lbs/plant, and in 2015- 0.61 lbs/plant. The berries were as numerous in 2014 but smaller sized in 2015. Fruit size in day-neutral plants is commonly 0.28-0.38 oz/fruit (Lantz, 2010). In 2014, all cultivars fell within this range, while in 2015, only ‘Portola’ and ‘San Adreas’ fell within the range. We observed larger berries from early season production, due to decreased temperatures, which are highly speculated as the reason for larger berry size (Poling, 2012; Wang and Camp, 2000; Kumakura and Shishido, 1994; Ruan et al., 2013a).

In comparing seasons, we observed the greatest significance in overall production during the mid-season for both production years from 1 July 2014 to 14 Aug 2014 and 1 July 2015 to 14 Aug 2015. Peak production occurred in July and decreased as temperatures rose throughout August into a modest fall production season. Rowley et al. (2011) with similar findings suggests that the temperature threshold for production occurred in July while the less late-season production was attributed to the hot Aug. which decreases pollination (Ledesma et al., 2005). High summer temperatures occurred at the end of July and throughout August in 2014 and 2015, after fruit development of the mid-season harvests. Strawberries have a 30-40 day cycle from anthesis to harvest (Symons et al., 2012), so effects of high summer temperatures towards the end of the mid-season were noticed in the late season fruit. Additionally, crown development occurs throughout the growing season, with increased crown numbers resulting in decreased fruit size (Poling, 2012). Similarly, we found early season harvests to produce larger fruit for all studied cutlivars. Consistent conditions during harvest, handling, and analysis of fruit were maintained each year, as seen with the percent marketability by weight differing by 3% from 2014 to 2015.

'Portola' had the highest total and marketable yield cultivar by weight during both years. 'Portola' also had the highest percent marketability by fruit number in 2015. 'Portola' was produced at the University of California at Davis and little testing has been performed outside California under these conditions (Lantz et al., 2010b). Similar to our findings, Ruan et al. (2013a) found 'Portola' to produce the highest marketable yields by weight in comparison to the other day-neutral cultivars at 1.16 lbs/plant. In addition, they observed that 'Portola' had two very large spikes in production in late season production in August and late-September. We found 'Portola' produced significantly larger berries in both 2014 and 2015 ($P < 0.0001$), at an average of 0.35oz/fruit. 'Portola' has shown through reasearch to produce a large, light colored fruit (Lantz et al., 2010b; Hoashi-Erdardt and Walters, 2013).

'Evie 2' produced high total yield in 2014 and 2015 from 1.16-0.82lbs/plant. Similar to our findings, 'Evie 2'is found to be most suitable for high-tunnels in terms of yield (Demchak et al., 2010, and Rowley et al., 2011), but Demchak et al. (2010), observed small berry size, which was similar to our results. Researchers from the University of Minnesota growing within a low tunnel found 'Evie 2' berries to produce an average of 1.16lbs/plant (Petran et al., 2016). Rowley et al. (2011) found great success in high-elevation high tunnel production in Utah with 'Evie 2' which displayed extreme heat tolerance and large berry size. Although we found ‘Evie 2’ to have high total yield, the fruit size was significantly small in comparison to the other cultivars studied and it was more susceptible to mold growth within the high tunnel ($P < 0.001$).

‘Seascape’ produced higher total yield with in 2014. Although we found ‘Seascape’ to have high total yields by weight, the fruit size was significantly small in comparison to the other cultivars studied. ‘Seascape’ is a popular day-natural cultivar, tending to have greater *Botrytis cineria* resistance and good yields (Demchak et al., 2010, and Rowley et al., 2011). We observed that ‘Seascape’ had higher marketability (by fruit number) in 2014. Hoashi-Erdhart and Walters (2014) found ‘Seascape’ cultivar showed significantly higher harvested yield in a similar study in high tunnels in Washington. Petran et al. (2016), found the ‘Seascape’ to produce 1.25 lbs/plant within low tunnels at two locations in Minnesota.

Similar to ‘Portola’, ‘San Andreas’ produced a significantly larger berry size in both 2014 and 2015 ($P < 0.0001$).’San Andreas’ produced significantly large fruit in 2014, but had the lowest yields by weight of the day-neutral cultivars. There is a lack of testing with ‘San Andreas’ outside of California. However, research shows that ‘San Andreas’ produces large fruit and has shown greater disease resistance (Lantz et al., 2010b; Hoashi-Erdardt and Walters, 2013). Similar to our findings, Ruan et al. (2013a), found ‘San Andreas’ produced low marketable yield. On the contrary, preliminary findings from a separate study by the University of Minnesota showed that ‘San Andreas’ produced an average of 0.990 lbs/plant in a low tunnel system (Petran et al., 2016).

Marketability by weight and fruit number were highest among ‘Albion’ and ‘Monterey’ in both growing years. Hoashi-Erhardt and Walters (2014) found both ‘Albion’ and ‘Monterey’ had lower percentage of culled fruit and higher marketable yields with ‘Albion’. While Ruan et al. (2013a), found ‘Albion’ produced low marketable yield within the high tunnel system at 0.65 lbs/plant. Petran et al., (2016) found that the total yield of ‘Albion’ was 1.04 lbs/plant in Minnesota low tunnels. In previous studies, ‘Albion’ has optimum color and size, but lower yield (Demchak et al., 2010). It is seen mostly in California, with an elongated shape, heavy foliage, and resistance to verticillium wilt (Lantz et al., 2010b). Poling (2012) predicts it to be late to yield but consistently strong during the summer and fall months. Similarly, our results indicate that ‘Albion’ is a strong cultivar in yield size in mid- and late season production.

‘Monterey’ produced also had significantly high marketability in weight and number in comparison to the all cultivars besides ‘Albion’. This is similar to the findings of Ruan et al. (2013a), who found the ‘Monterey’ cultivar to produce low marketable yields by weight at 0.740 lbs/plant. However, Petran et al., (2016), observed higher total yields by weight for ‘Monterey’ at 1.10 lbs/plant.

High tunnel systems are best suited for intensive cultivation practice of high value crops, because high tunnel growers maximize production in a limited space and with capitol expense. High prices are paid for strawberries in October and November, when strawberry production is lowest on a national scale (Belasco et al., 2006). High tunnel production allows for harvesting over a six-month period that ends in November or the first frost. High tunnel systems are meant to limit environmental variables like rain. The high tunnels used in our study were aligned next to each other with similar structures, and were controlled for ventilation based on wind patterns, internal soil temperatures, and maximum light exposure.

The results in EC show no significant difference in yield weight or size in either production year. We saw minor differences in increased fruit number. No previous research has implemented an evaporative cooling treatment within a high tunnel system on day-neutral cultivars throughout the entire production season. Further studies are needed to understand its potential in cooling the internal plant temperature. To control for environmental variables, a greenhouse study would more accurately represent the effects of the evaporative cooling on plant temperature and yields. Gray mold incidence was not affected by increased canopy moisture, therefore not affected by the EC.

Conclusion

Our results showed that production of day-neutral strawberries in high tunnels in the central U.S can be feasible with selected cultivars. We saw that mid-season production is the largest percent of total yield production by weight, while early season production was the largest percentage of total fruit sizes in both production years. All the cultivars studied fell within the desired weight and size range in 2014. In 2015, 'Evie 2' and 'Portola' fell within the desired weight range while 'San Andreas' and 'Portola' fell within the desired size range in 2015. We found that 'Portola' is highly successful for high tunnel strawberry growers in the central U.S. with high total and marketable yields by weight, number and size, along with high marketability. The evaporative cooling did not affect yield or disease pressure, although we saw conflicting differences among total fruit number between the two production seasons. To our knowledge, this is the first report of evaporative cooling system within a high tunnel for day-neutral strawberry cultivars. This data provides information for growers related to strawberry production within a high tunnel. Further trials are needed to identify the weather effect and best management practices in the region.

Table 1- Strawberry fruit yield of six day-neutral cultivars grown in a high tunnel at the Olathe Horticulture Research and Extension Center in 2014 and 2015

	Total Fruit Yield[z]			Marketable Fruit Yield[z]			Marketability[z x]	
	Weight (lbs/plant)[z]	Number (fruit/plant)[y]	Size (oz/fruit)[z]	Weight (lbs/plant)[z]	Number (fruit/plant)[y]	Size (oz/fruit)[z]	Weight (%)	Number (%)
Cultivar				**2014[wx]**				
Albion	0.85 bc	48.8 b	0.37 ab	0.75 bc	38.7 c	0.39 ab	88.6 a	84.4 a
Evie 2	1.16 ab	41.5 a	0.31 cd	0.93 ba	34.2 ab	0.33 cd	79.4 b	74.6 b
Monterey	0.88 bc	46.2 b	0.34 bc	0.75 bc	39.0 bc	0.35 bc	84.8 ab	82.2 a
Portola	1.33 a	43.1 a	0.39 a	1.12 a	35.4 ab	0.42 a	84.2 ab	79.5 ab
San Andreas	0.72 c	44.5 b	0.39 a	0.59 c	35.6 c	0.40 a	81.3 b	78.6 ab
Seascape	1.05 ab	50.3 a	0.29 d	0.89 abc	39.4 a	0.30 d	84.2 ab	81.4 a
P value[v]	***	***	***	**	***	***	*	*
Season Mean	**1.00**	**45.7**	**0.35**	**0.84**	**37.1**	**0.37**	**83.8**	**80.1**
				2015[wx]				
Albion	0.63 b	42.4 b	0.26 bc	0.52 b	30.7 b	0.27 bc	82.5 ab	78.1 a
Evie 2	0.82 ab	43.4 a	0.25 bc	0.62 b	33.3 ab	0.29 ab	76.5 b	68.0 b
Monterey	0.67 b	44.2 b	0.26 bc	0.57 b	35.8 ab	0.28 b	83.5 a	77.0 a
Portola	1.12 a	49.3 a	0.31 a	0.92 a	36.6 a	0.33 a	82.0 ab	77.1 a
San Andreas	0.62 b	41.7 b	0.28 ab	0.49 b	32.1 b	0.29 ab	78.9 ab	74.4 ab
Seascape	0.72 b	49.1 a	0.22 c	0.57 b	37.1 ab	0.23 c	79.2 ab	75.0 ab
P value[v]	**	*	***	***	*	***		*
Season Mean	**0.76**	**45.0**	**0.26**	**0.61**	**34.3**	**0.28**	**80.4**	**74.9**

[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[z]Means separation within a column within a year marked with the same letter do not differ ($P \leq 0.05$), Tukey's HSD Procedure.
[y]Parameters with non-significant differences between years, separated within a column ($P > 0.05$), Tukey's HSD Procedure.
[v] *,**,*** Significant at $P < 0.01$, 0.001 or 0.0001, respectively.

Table 2- Effect of evaporative cooling (EC) on the strawberry fruit number (fruit/plant) of the six day-neutral cultivars studied through 2014 and 2015 production season.

	Total Fruit Number [wx] (fruit/plant)			
Cultivar	Plots grown without EC		Plots grown with EC	
		2014[z]		
Albion	41.07	bcd	35.77	d
Evie 2	56.11	ab	47.90	abcd
Monterey	41.34	bcd	40.24	bcd
Portola	52.91	abcd	63.43	a
San Andreas	34.81	d	36.41	cd
Seascape	54.39	abc	50.13	abcd
Season Mean	**46.77**		**45.68**	
		2015[z]		
Albion	35.08	cde	37.34	bcde
Evie 2	63.14	a	53.95	abc
Monterey	34.19	de	45.86	abcde
Portola	52.89	abcd	55.07	ab
San Andreas	26.67	e	31.85	e
Seascape	60.52	a	56.21	ab
Season Mean	**45.41**		**46.71**	

[e]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments with and without evaporative cooling and sub-plots as cultivars.
[z]Means separation within a year marked with the same letter do not differ ($P \leq 0.05$), Tukey's HSD Procedure.

Table 3- Gray mold (incidence/plant) in the high tunnel with and without evaporative cooling (EC) during the 2015 production year.

Cultivar[xw]	**Before EC[y]** (incidence/plant)		**After EC[z]** (incidence/plant)	
		Plots with EC		
Albion	0.013	b	1.502	ab
Evie 2	0.013	b	3.738	a
Monterey	0.026	b	1.584	ab
Portola	0.051	b	1.584	ab
San Andreas	0.013	b	1.672	ab
Seascape	0.151	b	2.588	ab
		Plots without EC		
Albion	0.078	b	1.090	ab
Evie 2	0.063	b	3.493	a
Monterey	0.013	b	1.054	ab
Portola	0.051	b	2.292	ab
San Andreas	0.038	b	1.864	ab
Seascape	0.000	b	2.141	ab

[y]Before beginning EC applications (05/31/2015-07/13/2015).
[z]After beginning EC applications (07/13/2016-10/06/2015).
[x]Means separation within Table 3 marked with the same letter do not differ ($P \leq 0.05$), Tukey's HSD Procedure.
[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).

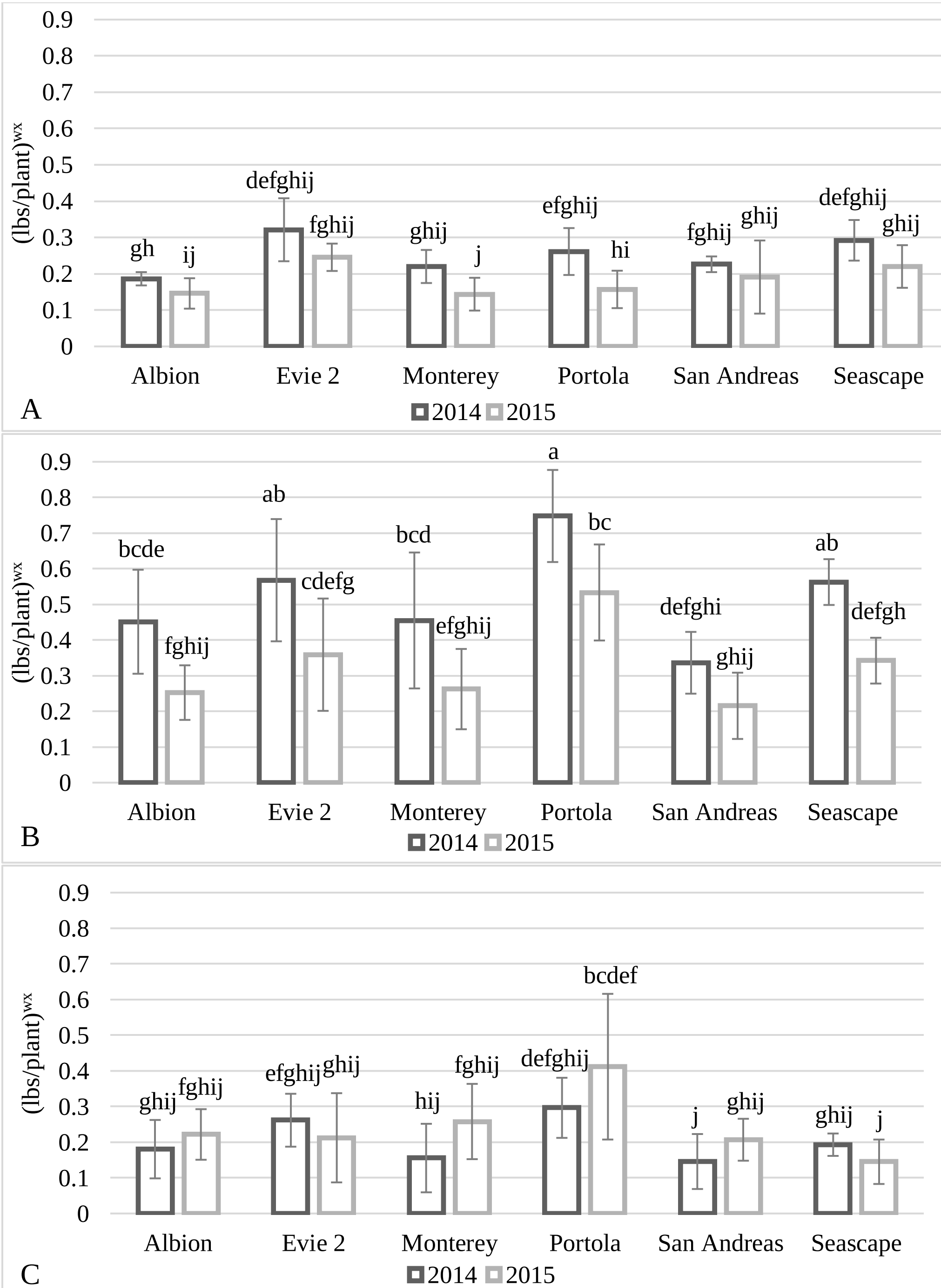


Figure 5- Total fruit yield (lbs/plant) of the six day-neutral strawberry cultivars studied at early (10 May 2014-31 June 2014, 31 May 2015-31 June 2015) A, mid-(1 July 2014-13 Aug. 2014, 1 July 2015-13 Aug. 2015) B, and late (15 Aug. 2014- 6 Oct. 2014, 15 Aug. 2015 -6 Oct. 2015) C season production throughout 2014 and 2015.

[z]Means within Figure 1A-1C marked with the same letter do not differ ($P \leq 0.05$), Tukey's HSD Procedure.
[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

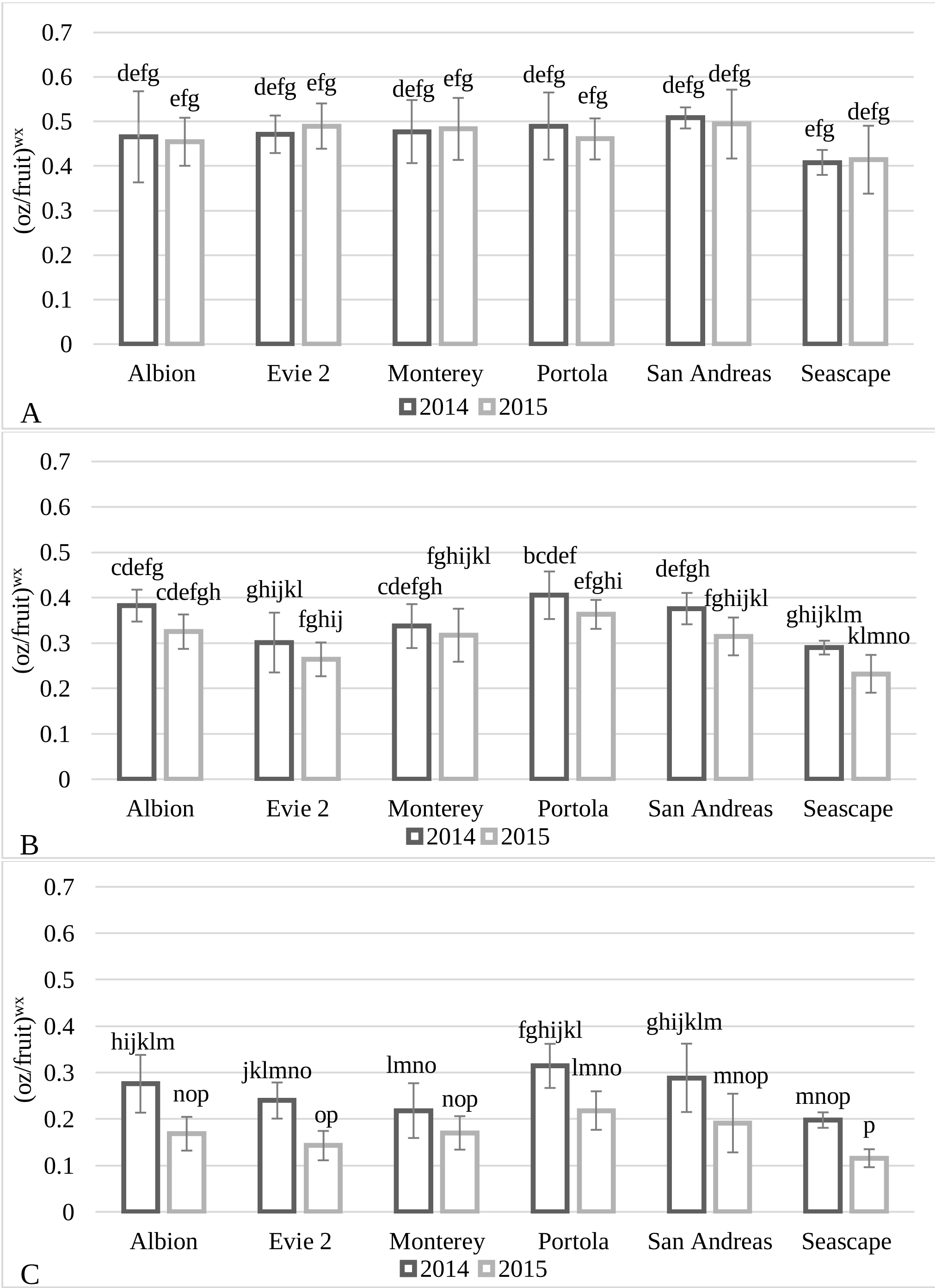


Figure 6- Total fruit size (oz/fruit) of the six day-neutral strawberry cultivars grown in a high tunnel at early (10 May 2014-31 June 2014, 31 May 2015-31 June 2015) A, mid-(1 July 2014-13 Aug. 2014, 1 July 2015-13 Aug. 2015) B, and late (15 Aug. 2014- 6 Oct. 2014, 15 Aug. 2015 -6 Oct. 2015) C season production throughout 2014 and 2015.

[z]Means within Figure 1A-1C marked with the same letter do not differ ($P \leq 0.05$), Tukey's HSD Procedure.

[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).

[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

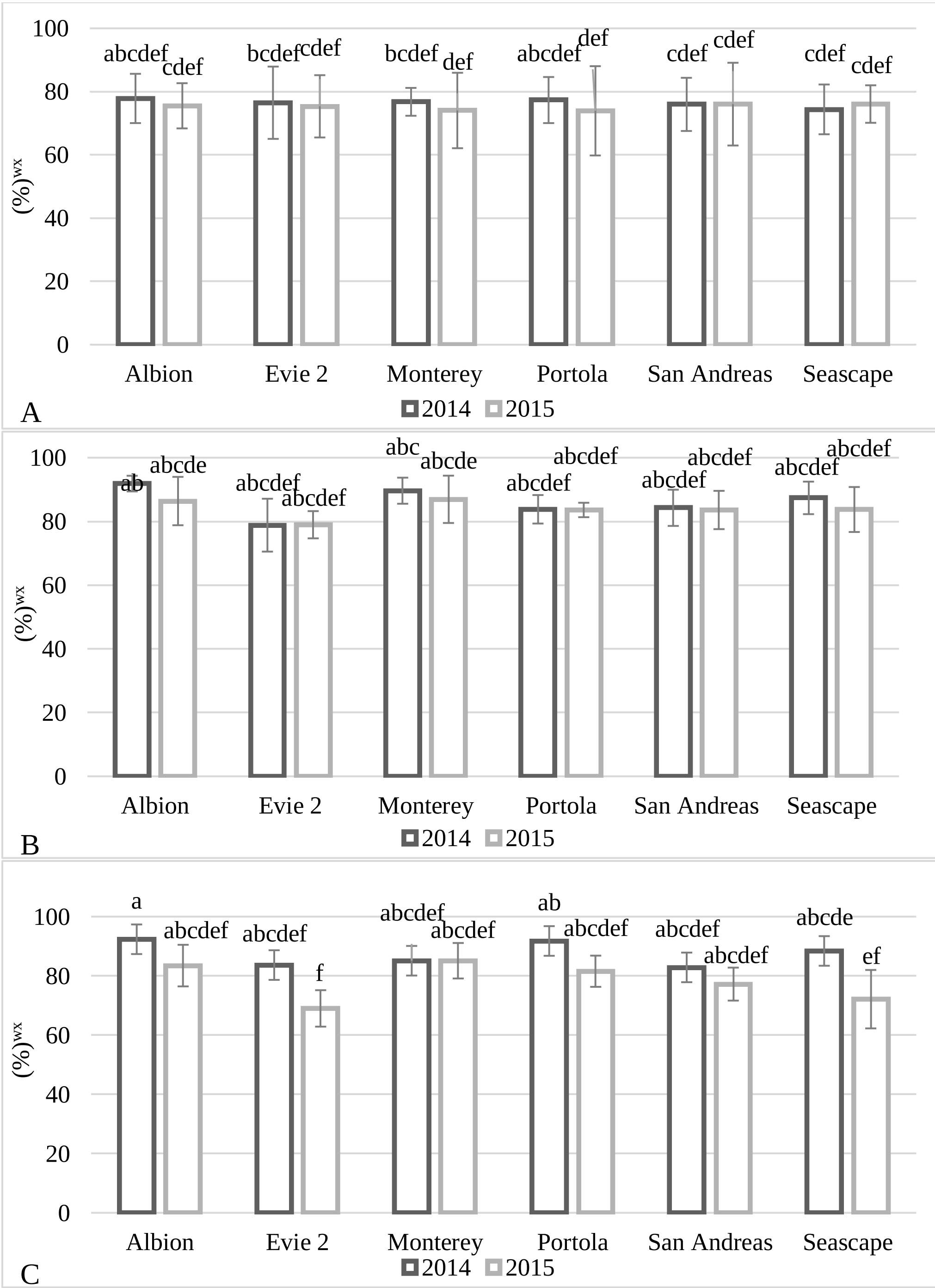


Figure 7- Marketability (%) of the six day-neutral strawberry cultivars grown in a high tunnel at early (10 May 2014-31 June 2014, 31 May 2015-31 June 2015) A, mid-(1 July 2014-13 Aug. 2014, 1 July 2015-13 Aug. 2015) B, and late (15 Aug. 2014- 6 Oct. 2014, 15 Aug. 2015 -6 Oct. 2015) C season production throughout 2014 and 2015.

[z]Means within Figure 1A-1C marked with the same letter do not differ ($P \leq 0.05$), Tukey's HSD Procedure.
[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Chapter 3 - Harvest and Postharvest Quality of the Spring-planted Day-neutral cultivars with the utility of Evaporative Cooling that perform optimally in High Tunnel Production

Abstract

Intensive specialty crop production within high tunnel systems in the central U.S. has greatly expanded. Spring-planted day-neutral production within this high tunnel production system, could provide growers with season extension and enhanced postharvest quality. This study identified which spring-planted, day-neutral strawberry cultivars are successful in a plasticulture, high tunnel system in regards to at-harvest and postharvest quality, while investigating the utility of evaporative cooling. The trial was conducted at Kansas State University Olathe Horticulture Research and Extension Center (OHREC) during 2014 and 2015. Six commercially-available cultivars were evaluated: ‘Albion’, ‘Evie 2’, ‘Monterey’, ‘Portola’, ‘San Andreas’, and ‘Seascape’. Mature fruit (90-100% red) was harvested twice weekly and four harvests were evaluated for at harvest and postharvest quality throughout each production year. Postharvest storage was monitored every 24hrs by respiration rate, moisture content and overall visual quality, using a scale from 5 (excellent) to 1 (very poor). Physical and organoleptic quality measurements (texture and color, and soluble solids and titratable acidity) were evaluated every two days throughout storage. Nutritional quality (total phenolic and antioxidant availability) was evaluated at harvest. Our results show that soluble solids content (°Brix) was highest with ‘Monterey’ and ‘Albion’ ($P < 0.0001$), while ‘San Andreas’, ‘Monterey’, ‘Portola’, and ‘Albion’ retained firm texture ($P \leq 0.0001$). All cultivars maintained their overall visual quality until day 8, with the exception of ‘Evie 2’ and ‘Seascape’. Furthermore, the four cultivars maintained

visual quality and had lower respiration rates and moisture content loss ($P < 0.001$, $P < 0.0001$, $P < 0.05$). Throughout storage, 'Seascape' had a high respiration rate ($P < 0.0001$) and low overall visual quality ($P < 0.01$). Moisture content loss throughout 2014 was less than in 2015 ($P < 0.0001$) and 'San Andreas' and 'Monterey' had the least moisture loss throughout both production seasons ($P < 0.01$).

Introduction

Fresh strawberry production in the U.S. is a 2.6-billion-dollar industry, with the majority of strawberries grown in the U.S. consumed fresh (~80%) (UDSA NASS, 2015). The U.S. per capita consumption of fresh strawberries was 7.9 lbs/person in 2013 and was forecasted to continue increasing (Perez and Plattner, 2014). Strawberries contain phytochemicals which have positive effects on health along with a characteristic aroma, bright red color, juicy texture, and sweetness (Yang et al., 2011). In numerous studies, it has been shown that strawberries have health-promoting benefits as an antioxidant-rich food (Aaby et al., 2012; Wolf et al., 2016; Ames et al., 1993; Joseph et al., 1999). Antioxidant-rich foods inhibit oxidation of human low-density lipoproteins and aid in prevention of various human diseases caused by oxidative stress; strawberry extract has been shown to reduce age-related motor and cognitive deficits in aged rodents (Ames et al., 1993 and Joseph et al., 1999). Anthocyanin is the main antioxidant in strawberries and is shown in research to have greater activity than other common antioxidants such as ascorbate, glutathione, etc. While phenolic acids make up the largest percentage of total phenolic content in strawberries, with ellagic acid was the main phenolic compound (Häkkinen et al. 1999).

California produces 91% of the world's strawberry crop, relying on mass-transit to move the product around the U.S. and internationally (NASS, 2015). Shipping fruit long distances can encourage harvesting at less than ideal maturity, resulting in suboptimal taste quality to the consumer due to immature fruit and decreased availability of key antioxidant nutrients (Kader, 1995; Lantz et al., 2010b). Shewfelt (1990) observed that 5-10 days of transportation results in 30-50% decrease of nutritional constituents. Strawberries are non-climacteric fruit, and ripen only while still attached to the parent plant. The strawberry flavor suffers when harvested before they are fully ripe because their sugar and acid contents do no increase after harvesting, resulting in a sour taste. Maturation and ripening are gradual processes, and fruit should be harvested at full maturity (>75% red) for optimal quality (Shewfelt, 1990; Sirivatanapa, 2006).

Resourcing locally grown strawberries is a solution to the negative effects experienced by long distance transportation on the quality of fresh strawberries. Freshness and proximity are related as the relationship between longer transportation times, can result in a decrease in nutritional quality (Srivatanapa, 2006). It is reported that the top three reasons that consumers support local food in the U.S. in order of importance are freshness, support of the local economy, and taste (FMI, 2014).

Perennial production systems used to be the norm for local production in the central U.S. However, because of decreased yields and size, commercial strawberries are often on an annual production system (Strik et al., 1996). The majority of strawberries grown in the central and southern U.S. are fall-planted June-bearing cultivars grown in open-field plasticulture systems. The harvest season of the June-bearing cultivars in Kansas is approximately 4-6 weeks long (May to early-June) (e.g. ‘Chandler’ & ‘Camarosa’), which aligns with peak national production, drives prices down, and increases competition for product distribution (Rowley et al., 2011; Juaron and Klein, 2011).

Kadir et al., (2006a) observed success with June-bearing strawberries grown in Kansas high tunnels in regards to yield, plant growth and fruit quality. High tunnel production of strawberries in Kansas has potential of producing early crops and extending the production season in comparison to open-field systems (Kadir and Carey, 2004). Extension specialist, Phelps (2014), suggests that high tunnels add to the productivity of the crop when utilized for protection from wind, birds, and harsh weather; and minimize disease pressure with less moisture on foliage. Kadir et al. (2006a) observed success with June-bearing strawberries grown in Kansas high tunnels in regards to yield, plant growth, and fruit quality with early-season production due to 5-12°C warmer soil conditions. Size of berry, soluble solids content, yields, branch-crown development, and plant vigor were greater within the tunnel. This is in agreement with Voca et al. (2007), who found that in comparing high tunnel, open-field, and hydroponics systems with June-bearing cultivars in Zagreb, Coatia, soluble solids and Vitamin C content was greatest within the high tunnel system.

Fall-planted June-bearing cultivars in an open-field production system traditionally focuses on fruit production in the early spring (Black et al., 2002; Poling, 1993), but the length of fruiting season is limited by photoperiod and temperature (Durner et al. 1984). Day-neutral cultivars are insensitive to photoperiod and will continue to grow and produce fruit as long as temperatures are between 40-85°F (Rowley et al., 2011). Because they can be planted in the spring, day-neutral cultivars grown in a high tunnel production system have the ability to produce optimal yields without requiring production space during the winter (Demchak et al., 2010; Heidenreich et al., 2007; Lantz et al., 2010b). Recent research compares the postharvest quality of day-neutral to June-bearing cultivars grown within a high tunnel production system (Petran et al., 2016). The researchers found that the day-neutral plants yielded greater fruit yield and higher total soluble solids content than June-bearing cultivars (i.e. 12.24°brix in low tunnels for day-neutrals compared to 7.6°brix for the June-bearing trial under the same growing conditions) (Petran et al., 2016). A study in Florida with June-bearing cultivars found that strawberries grown within the high tunnel had 7.5% greater soluble solids content than those grown in the open-field system (Donoso, 2009).

The postharvest quality of strawberry fruit is affected largely by environmental factors like sunlight, temperature, environmental exposure, irrigation, and cultivar (Kader, 1999). However, photoperiods and temperature requirements differ between cultivars (Heide, 1977). Darrow (1936) was one of the first researchers to report that the photoperiod based on temperature and day length induced flower formation in strawberries, which varied by regional adaptation of the cultivars. Typical time from anthesis to harvest is 30-40 days, when environmental factors influence fruit quality (Symons et al., 2012). Temperature affects the rate of nutrient uptake and metabolism, strawberry color development, and firmness. Transpiration increases as temperature increases; therefore, increasing nutrient supplies due to optimal light and temperature (Kader, 1999). Wang and Camp (2000) observed that soluble solids (SSC), titratable acids (TA), fruit color, fruit quality, and fruit size decreased with high temperatures. The change in exposure to daylight and temperature can affect antioxidant properties and sugar content, because of effect on the maturation process (Gunduz and Ozdemir, 2014; Wang and Camp, 2000; Ordidge et al., 2010). High temperatures >85°F experienced in the central U.S., have been shown to delay strawberry flower initiation and development (Phelps et al., 2012; Petran et al., 2016, Poling, 2012) and decrease firmness and sugar content (Voca et al., 2007; Wang and Camp, 2000).

The use of shade cloth and evaporative cooling might aid in overcoming these problem (Lantz et al., 2010b; Roos and Jones, 2012; Johnson, 2011). High temperatures from 95-104°F is detrimental to photosynthesis and productivity (Kadir et al., 2006b). Kadir et al. (2006b) suggests that variability amongst cultivar may tolerate heat exposure at different temperatures. Strawberry hormone levels are based on the genotype which have shown to determine postharvest quality aspects. Hormone levels of absicic acid (ABA) begin rising 2 weeks prior to harvest after the fruits change from green-to-white, at the same time that indole-3-acetic acid (IAA) and Gibberellic acid (GA) decrease (Symons et al., 2012). The increase in ABA levels observed during fruit development coincides with the onset on color (Symons et al., 2012), and has been reported to increase anthocyanin levels (Jia et al., 2011), and stimulate sucrose in in-vitro applications (Archbold, 1988).

Rowley et al. (2011) studied high tunnel production in high-elevation Utah. Although it wasn’t a part the studied variables, they found that shade cloth reduced internal high tunnel temperatures by 40°F to increase yields of day-neutral cultivars, while also increasing temperatures by 40°F in winter months. The extension specialists, Phelps (2014), suggests proper ventilation to increase air circulation, and overhead misters to decrease plant temperatures in the central U.S.

Evaporative cooling is a common technique to reduce damage from heat stress in orchards, and it can impact pest and disease pressure, fruit maturity, fruit storage characteristics, fruit color development, seasonal irrigation water requirements, and irrigation scheduling. (Lantz et al., 2010b; Koike et al., 2009). Previous research has focused in apple and pear production to reduce sunscald and extend storage life (Parchomuchuk and Meheriuk, 1996; Van Den Dool, 2006; Evans, 2004). Overhead sprinkling is a technique studied in commercial-scale open-field strawberry production for the impacts on yield, plant health, pest damage, powdery mildew, Botrytis cinerea, and soil salinity as reported by extension specialist, Dara (2012 & 2016). In a high tunnel or greenhouse, the increased humidity can result in decreased pest pressure (Dara, 2012). The purpose of implementing evaporative cooling in Kansas summer months of July and August, is cool the internal temperature of the berries and produce better quality fruit. To our knowledge, no studies have been conducted on the use of evaporative cooling for day-neutral production within a high tunnel system in Kansas. Implementing evaporative cooling in this specific production system could benefit plant and berry quality while providing the market with locally grown strawberries. The objectives of this work were to identify spring-planted day-neutral cultivars that perform optimally in a Kansas high tunnel production system by evaluating the physical and nutritional quality at harvest and during storage, and to determine how weather conditions and evaporative cooling affects crop performance regarding nutritional quality, and storage life for high tunnel strawberry production.

Materials and Methods

High tunnel trials were conducted at the Kansas State University Olathe Horticulture Research and Extension Center (OHREC) during 2014 and 2015, and a full description is provided in Chapter 2. Strawberries were grown under a three-season high tunnel (200' x 24') with 30% shade cloth, applied once daytime temperatures were consistently around 85°F. We used a split-plot design with four replications; only the harvest and postharvest quality data from the 2014 and 2015 production season data is displayed in this paper. The main plots included the use of evaporative cooling (with and without) and the sub-plots consisted of the six cultivars. Six cultivars were: 'Evie 2' (Edward Vinson Breeders in Kent, England), 'Albion', 'Monterey', 'Portola', 'San Andreas', and 'Seascape' (all from University of California at Davis).

Evaporative cooling was applied once summer temperatures reached 85°F by 12:00pm (10-minute application) (as described in Chapter 2). The strawberries were harvested once or twice weekly at commercial ripeness (90%-100% red ripe) and were sorted, and counted for yield and marketability. Four times per growing year, during peak yield periods, fruit was harvested for at harvest and postharvest analysis. Because of high quantity, fruit was combined within cultivar and separated by evaporative cooling treatment. Strawberry fruit were transported in an air-conditioned vehicle to the postharvest laboratory at KSU-Olathe for evaluating storage life, organoleptic, physical and nutritional quality. Fresh fruit was sorted, based on maturity at 90-100% mature, free from visual defects or damage, and uniform size and color. Strawberries were stored at a constant 3°C and 90-95% relative humidity in environmental chambers (Forma Environmental Chambers, ThermoFisher Scientific Inc., Asheville, NC) until the end of their storage life.

Physical Quality

Physical quality was evaluated destructively with texture and color measurements at harvest and every two days for the 7 to 8 day storage life period. Three replications of four fruit per rep. were measured for every parameter. Texture was measured with a texture analyser TA-58, TA.XT.plus (Texture Technologies Corp., Scarsdale, NY, USA), using an 8mm diameter cylinder probe. The following parameters were evaluated: firmness, springiness, cohesiveness, adhesiveness, gumminess, chewiness, and resilience and described by Caner (2008). Two measurements were taken on opposite shoulder sides of the berry. Color measurements were determine using an A5 Chroma-Meter Minolta CR-400 (Minolta Co. Ltd., Osaka, Japan). Color results were expressed as CIELAB color system, L* is lightness, a* (-greenness to +redness), and b* (-blueness to +yellowness) was used to determine differences between cultivars (Bakker et al., 1986). Immediately following the destructive measurements for physical quality, the fruit was frozen with liquid nitrogen and stored at -20°C for analysis of the organoleptic, and nutritional quality.

Organoleptic Quality

Organoleptic quality was measured destructively at the day of harvest and during storage (every two days) over the course of the 7-8-day storage period. Three replications of four fruit/rep. were measured for every parameter. The frozen berries were macerated with a mill (IKA Laboratory, Analytical & Processing Equipment, Wilmington, NC). Aliquots of 5g were thawed and extracted for hydrophilic portion and lipophilic portion (Cao et al., 1995). Titratable acidity (TA) was measured with an automatic titrometer (Compact Titrosampler 862, Metrohm USA Inc. Riverview, FL.) and the results were expressed as % of citric acid equivalent (AOAC International, 1995). Soluble Solids Content (SSC), was obtained with a drop of juice using a refractometer (Reichert Technologies, Depew, New York) and expressed as °Brix.

Nutritional Quality

The remaining hydrophilic and lipophilic portions of the fruit samples were destructively analyzed for total antioxidant and total phenolic measurements. Determination of total phenolic content was measured according to the Singleton and Rossi (1965) procedure. Using a 96-well microplate reader (Synergy H1, BioTek Instruments, Inc. Winooski, VT, USA) at 750nm absorbance, the results are expressed as mg gallic acid equivalent in kg fresh weight basis (GAE/kg FW). Determination of the total antioxidant capacity was measured according to Benzie and Strain (1996), with the Ferric Reducing Ability of Plasma (FRAP) method. Using the 96-well microplate reader with the spectrophotometer at 593nm, absorbance was determined against the trolox positive control and expressed as micromolar trolox equivalent in 100g fresh weight basis (μM TE/100g FW). Determination of the antioxidant capacity was described by Cao et al. (1993) and modified by Ou et al. (2001) and Prior et al. (2003), measuring the Oxygen Radical Absorbance Capacity (ORAC) adapted for a 96-well microplate fluorometer. Antioxidant activity was correlated with the oxidative damage to the fluorescent probe against the trolox positive control and expressed as micromolar trolox equivalent in kg fresh weight basis (μM TE/100g FW).

Overall Visual Quality

Fruits were non-destructively evaluated every 24 hours for overall visual quality throughout their storage life (~8 days). Twenty berries per cultivar and treatment were separated for overall visual quality free from damage and at similar maturities. Overall visual quality was evaluated by using the scale provided by Nunes (2010) with scores from 5 to 1 (5-excellent to 1-very poor) (Figure 5). Fruit was considered unmarketable once 30% of the population fell below a 2.5 on the overall visual scale. The scale was customized slightly to categorize the 90-100% red freshly harvested berries as a '5', instead of a '4.5' as the scale suggests (Figure 9). The overall visual quality was analyzed with area under the curve measurements. Area under the curve (AUC) from plant disease progression analysis was performed as it is a better analysis method for overall visual quality measurements, which don't progress linearly. AUC analysis for overall visual quality shows a clearer effect rate decrease between the studied day-neutral cultivars (Shaner and Finney, 1997).

Respiration Rate

Respiration rate (mg CO_2/kg-h) was determined by a closed or static system as was described by Biale and Young (1981). The portable gas analyzer (model 900141; Bridge Analyzers, Alameda, CA) with three replications of four fruit per replications was used for every parameter. Berries were kept sealed in air-tight glass jars (0.75L Le Parfait Jars) for 60 minutes prior to the measurements. Measurements were taken every 24 hours throughout storage.

Moisture Loss

Moisture Loss was measured daily by weight measurements of the same berries used for respiration measurements. The observed differences in weight measurements resulted in the final weight loss expressed as percent weight loss over the cultivars storage life as described by Bourne, 1976.

Statistical Analysis

This paper displays the quality attributes at harvest and during storage that were measured during the two years of the experiment. The four harvests from each year were evaluated for physical, organoleptic, and nutritional quality parameters. To evaluate the significant ($P \leq 0.05$) effect of the cultivars, treatments, and environmental temperatures, regression models were built to determine which factors and interactions between factors affected the many quality parameters of the strawberries at harvest and during storage. Since we were interested in which factors and levels within the factors had greater influence on the quality parameter, regression was found to be more appropriate analysis tool in addition to ANOVA. ANOVA provides an overall assessment of the importance of a factor without elaborating on the significance within each factor.

Because weather was an uncontrolled parameter that was analyzed, its effect to the response varied retrospectively. The environmental conditions that were used were based on the minimum, maximum, and average temperatures, as well as the average humidity experienced the two weeks leading up to each harvest date. Because harvests were often within 30-40 days of one-another (the estimated time from anthesis to harvest), the weather data was an accumulation of two weeks prior to harvest. The historical weather summary for OHREC was provided from the weather data library from Kansas Mesonet, which takes hourly measurements of air temperature, relative humidity, precipitation, 2” soil temperature, and 4” soil temperature. The two-week weather summary prior to the eight harvests was analyzed for its effect on the quality parameters throughout the two years of the experiment. Two weeks is the expected time period from the immature small-white berry to the harvest date, during which time the berry quality is sensitive to environmental influences (Symons et al., 2012). Minimum temperature events experienced within two weeks prior to the eight harvests were within the range of 33.4°F-68.4°F. Maximum temperature events experienced within two weeks prior to the eight harvests were within the range of 88.7°F-99.5°F. The mean of the average temperatures experienced two weeks prior to the eight harvests throughout the two growing seasons was 70.1°F-81.5°F. The mean of the average humidity experienced two weeks prior to the eight harvests throughout the two production seasons were 70.02%-76.09%.

Significant differences between mean cultivar responses, treatment, production year, and weather effects were separated using pairwise comparisons Student’s t-tests at 0.05 level. Each value in the tables is expressed as mean and values in figures are expressed mean ± standard deviation. Data were analyzed by JMP Systems (JMP, version 13, SAS Institute Inc., Cary, NC 1989-2007).

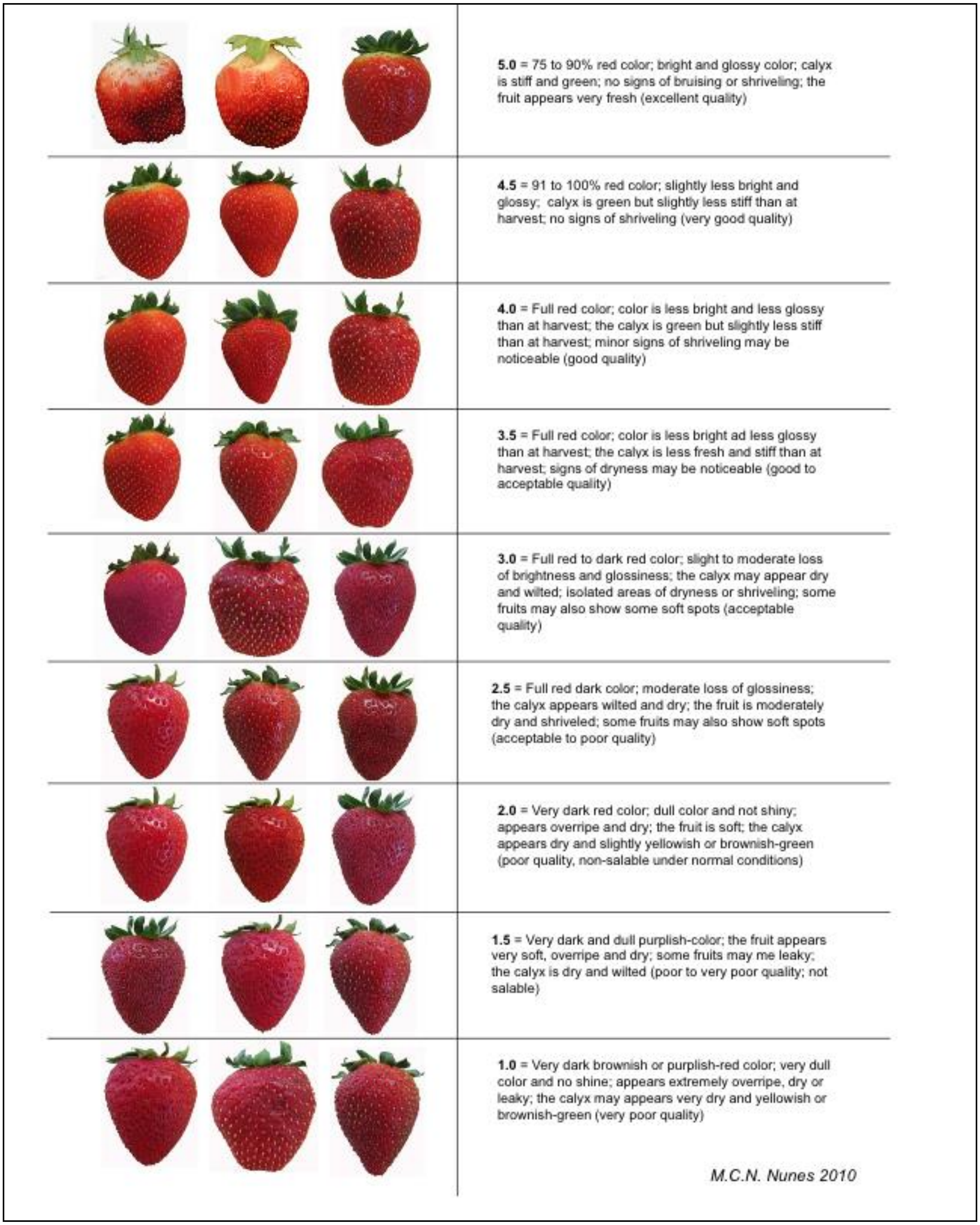


Figure 8- Overall visual quality parameters ranging from 5 (excellent) to 1 (poor).

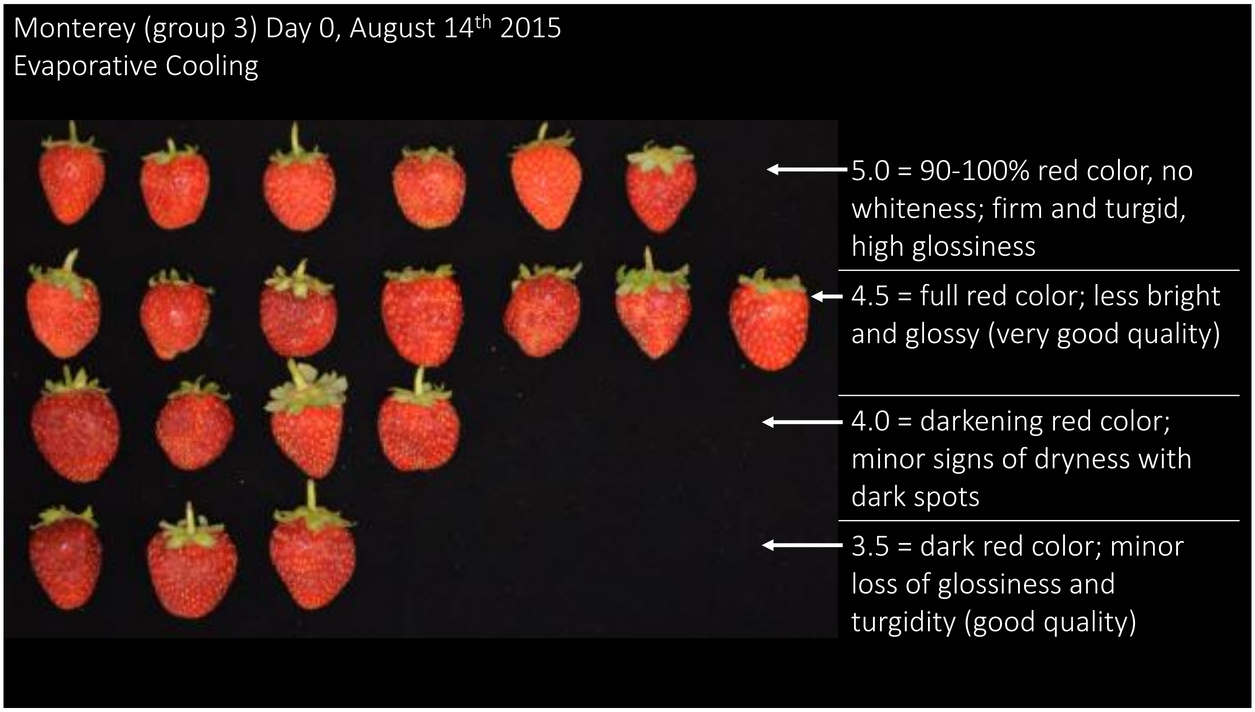


Figure 9– 20 fruit from each day-neutral cultivar were selected to represent the harvest population and analyzed daily for overall visual quality for a total of 7-8 days throughout storage.

Results

Physical Quality

Firmness was significantly different across all cultivars ($P < 0.0001$) (Table 4). The fruit firmness at harvest was significantly higher for the following cultivars in descending order: 'San Andreas', 'Albion', 'Monterey', and 'Portola' (Table 5). While 'Seascape' and 'Evie 2' were significantly less firm berries ($P < 0.0001$) (Table 5). Throughout storage, all cultivars were most firm on day 2 of storage and softened by day 7 (Figure 10). Evaporative cooling (EC) did not affect the firmness at harvest in either years of the experiment (Table 6), but 'Portola' produced berries with slightly higher ($P < 0.05$) firmness composition when applied with EC throughout storage (Table 6). Firmness measurements were not varied between production years. Additionally, weather did not significantly affect the strawberry firmness (force (g)) throughout either production season (Table 4).

Color index a* was significant among all cultivars ($P < 0.001$) on day of harvest (Table 8). Strawberries from the 'Monterey' and 'Albion' cultivars had inherently less red color ($P <$ 0.01 and 0.01, respectively) (Table 5). Strawberries grown from the 'San Andreas' cultivar were significantly more red ($P < 0.01$) (Table 5). Throughout storage, berries were significantly more red on day 0 and day 2 of storage ($P < 0.01$ and 0.05, respectively) while all cultivars were significantly less red on the final day of storage ($P < 0.0001$) (Figure 11). Evaporative cooling did not affect the color index a* at harvest during either production seasons (Table 8) or throughout storage (Table 9). Redness color (a*) measurements varied between production years, with less redness (a*) seen in all cultivars in the 2014 growing season than in the 2015 growing season ($P \leq 0.001$) (Table 8). However, weather conditions significantly affected berry redness, where all strawberry cultivars increased redness (a*) as maximum temperatures increased ($P \leq$

0.01) (Table 8). All strawberry cultivars decreased redness (a*) when minimum temperatures fell ($P < 0.05$) (Table 8), with the exception of 'Monterey' that increased redness (a*). Similar to maximum temperature- when the average humidity rose, all strawberry cultivars increased redness (a*) ($P < 0.01$) (Table 8), with the exception of 'Monterey' that decreased redness (a*) slightly.

Color index L*of the strawberries was significant amongst all cultivars ($P < 0.0001$) (Table 10). 'Albion' and 'Monterey' strawberries were significantly darker berries (low values in color index L*) in comparison to the other cultivars ($P < 0.0001$ and 0.0001, respectively) (Table 5). 'San Andreas' was the lightest cultivar (high values in color index L*) of the cultivars studied ($P < 0.0001$), with 'Seascape' in a close second (Table 5). Throughout storage, the strawberries of all cultivars were lightest on the day of harvest ($P < 0.001$) and became darker throughout storage, with a significant decrease in color index L* by the final day of storage ($P < 0.0001$) (Figure 12). There was no effect observed from evaporative cooling on the lightness of the strawberries at harvest in either year (Table 10). The exception was the interaction between 'Monterey' x treatment [without EC], whose fruit was slightly lighter throughout storage in 2014 ($P < 0.05$) (Table 11). Color index L* measurements were varied between production seasons (Table 10). Berries produced during the 2015 production year were significantly more light (L*) than those produced in 2014, but only with a minor difference ($P < 0.05$) (Table 10). An exception occurs at the interaction between 'San Andreas' because the berries were significantly less light in 2015, than in 2014 (Table 10). Weather conditions had a large effect on berry lightness, including minimum temperatures, average temperatures and average humidity. Strawberries from cultivars were significantly darker (low values in color index L*) as minimum temperatures fell ($P < 0.01$) (Table 10) ($P < 0.01$). The exception was the interactions between the cultivar ‘Albion’ x Min. Temp ($P \leq 0.01$), and ‘Seascape’ x Min. Temp ($P < 0.01$), where strawberries increased lightness (L*) as minimum temperatures fell (Table 10). The effect of average temperature was highly significant ($P < 0.0001$), and strawberries tended to be lighter in color as the average temperature increased (Table 10). However, small interactions occurred between ‘Albion’ x Avg. Temp. ($P < 0.01$) and ‘Seascape’ x Avg. Temp. ($P < 0.05$) whose changes in lightness were independent of the average temperatures (Table 10). The effect of average humidity ($P \leq 0.01$) was slightly significant (Table 10), as humidity increased, the color of the strawberries would become darker. The exception was the interactions between the cultivar ‘Albion’ x Avg. Humidity ($P < 0.01$), and ‘Seascape’ x Avg. Humidity ($P < 0.01$), where strawberries increased lightness (L*) as average humidity increased (Table 7).

Organoleptic Quality

Soluble solids content was significantly different among the cultivars tested ($P < 0.001$) at the day of harvest (Table 13). ‘Albion’ and ‘Monterey’ contained the highest levels of soluble solids amongst all the cultivars at 7.77°Brix and 7.65°Brix, respectively (Table 12). ‘Evie 2’ and ‘Portola’ contained significantly lower soluble solids content at 6.46 and 6.33°Brix (Table 12). Throughout storage, both cultivar and storage day factors significantly affected the soluble solids content ($P < 0.001$ and $P \leq 0.0001$, respectively) (Table 14) (Figure 13). Soluble solids content increased significantly throughout storage with the greatest increase experienced by each cultivar day 4 of storage ($P < 0.01$) (Figure 13). The largest increase of SSC throughout storage was detected in strawberries for ‘Portola’ cultivar throughout storage ranging from 6.60°Brix at harvest to 7.2°Brix at day 4 of storage ($P < 0.0001$). Evaporative cooling did not affect the SSC at harvest (Table 13) or during storage both years of the experiment (Table 14). Soluble solid content was not varied between the two production years (Table 13). However, when maximum temperatures increased throughout the two production years, the soluble solids content tends to decrease ($P \leq 0.01$).

The effect of the cultivar factor on the titratable acidity at the day of harvest was significant ($P < 0.0001$) (Table 15). Individually, ‘Albion’ and ‘Seascape’ contained significantly greater %TA at 0.936 and 0.927 %TA ($P < 0.01$ and $P < 0.01$, respectively) (Table 12). There were no significant effects seen throughout storage on the %TA (Table 16). There was no observed effect from the evaporative cooling treatment on the titratable acidity of the strawberry at harvest. However, the strawberries produced with evaporative cooling contained slightly lower titratable acids throughout storage ($P < 0.05$) (Table 16). Titratable acidity was not varied between the two production years. Similar to SSC, the increasing maximum temperatures had a slightly negative effect on the %TA across all cultivars ($P < 0.05$) (Table 16). As observed in all cultivars, when the maximum temperature increased- the titratable acidity decreased (Table 16).

Nutritional Quality

The fruit from the cultivars ‘Evie 2’ and ‘Seascape’ contained significantly higher levels of total antioxidant content the day of harvest according to the ORAC (μM TE/100g FW) method ($P < 0.0001$ and $P \leq 0.01$, respectively) (Table 17). Whereas, the fruit from the cultivar ‘Portola’ had significantly lower total antioxidant content according to the ORAC method in comparison to all other cultivars ($P < 0.0001$) (Table 17). Evaporative cooling did not affect the ORAC levels in the strawberries at harvest during either production years (Table 18). The total antioxidant content ORAC (μM TE/100g FW) levels were significantly different between production years ($p<0.0001$) (Table 18), with 27% higher season mean in 2014 than in 2015. Changes in total antioxidant measured with the ORAC method were all independent of the weather factors (Table 18).

The following day-neutral cultivars contained similar levels of total antioxidants through the FRAP analysis in descending order: ‘Monterey’, ‘Evie 2’, ‘San Andreas’, Seascape’, and ‘Albion’ (Table 17). ‘Portola’ was significantly low in antioxidant capacity with the FRAP method at ($P < 0.0001$) (Table 17). Evaporative cooling did not affect the FRAP levels throughout either year of the experiment (Table 19). FRAP (μM TE/100g FW) levels were significantly different between production years ($P < 0.0001$) (Table 19), with a greater season mean in 2014 than in 2015. As maximum temperatures increased throughout the two production seasons, the FRAP content tends to decrease ($P < 0.0001$) (Table 19). All cultivars experienced decreased FRAP content under maximum temperatures. On the contrary, as average temperatures increased throughout the two production seasons, the FRAP content tends to increase ($P < 0.0001$) (Table 19). All cultivars had increased FRAP content as average temperatures increased ($P < 0.0001$) and slight increases in FRAP content ($P < 0.05$) with an increasing average humidity (Table 19).

‘Evie 2’ was the cultivar that produced fruit with the highest total phenolic content of the day-neutral cultivars studied ($P < 0.001$) (Table 17). On the other hand, the ‘Portola’ cultivar produced fruit with the lowest total phenolic content of the day-neutral cultivars studied ($P < 0.0001$) (Table 17). The evaporative cooling treatment significantly affected the total phenolic content within both production years ($P < 0.0001$) (Table 20). In comparing the evaporative cooling treatment means, the fruit grown without evaporative cooling contained higher total phenolic content. Total Phenolic Content (GAE/kg FW) within day-neutral strawberries was similar across both growing years (Table 20). However, weather factors significantly affected the total phenolic content among all cultivars (Table 20). As the minimum temperatures increased, the total phenolic content fell ($P < 0.0001$) (Table 16). Similar to FRAP in regards to weather, as average temperature and average humidity increased, the total phenolic content increased ($P < 0.0001$ and $P < 0.0001$, respectively) (Table 20).

Moisture Loss

Moisture loss was significantly different among the day-neutral cultivars in this study ($P < 0.01$) (Table 22). ‘San Andreas’ and ‘Monterey’ had the least moisture loss at 7.06% and 7.16% in comparison to ‘Evie 2’ and ‘Seascape’ ($P \leq 0.05$) (Table 21). ‘Seascape’ had the highest moisture loss throughout storage at 10.7% ($P < 0.001$) (Table 21). Evaporative cooling did not affect the moisture loss throughout storage during either production season (Table 22). However, moisture loss (%) varied between production seasons. The 2014 production season experienced significantly more ($P < 0.001$) moisture loss (%) in comparison to 2015 (Table 22). The moisture loss percentage 2015 seasonal mean decreased an average of 32%, but ‘Portola’ and ‘Seascape’ were largely affected by the production season, with observed 44.4% and 37.1% decrease in moisture loss from 2014 to 2015.

Respiration Rate

The respiration rate was not significantly different between the two growing years (Table 23). A significant difference existed among cultivars ($P < 0.0001$) (Table 23). Fruit from from the ‘Seascape’ cultivar dramatically respired in comparison to the other cultivars (Figure 8 and 9). No significant difference existed among the other five cultivars, but ‘Albion’ and ‘Portola’ maintained the lowest respiration rates (Table 21). The respiration ranged from ‘Seascape’ at the highest from 21.42 to ‘Albion’ as the lowest respire at 12.6 mLCO_2/kg-h (Table 21). The evaporative cooling treatment did not affected the respiration rate during either production seasons (Table 23).

Overall Visual Quality

Overall visual quality of the strawberry day-neutral cultivars was higher ($P < 0.05$) in the following cultivars in descending order: 'San Andreas', 'Monterey', 'Albion', and 'Portola' (Table 21). 'Seascape' and 'Evie 2' scored significantly lower than the other cultivars ($P < 0.01$ and $P < 0.01$, respectively) (Table 23). There was no effect of evaporative cooling treatment on the overall visual quality throughout either production season (Table 23).

Discussion

Quality components between cultivars ultimately depends on consumer preference (Kader, 1992). Consumers, marketers, and economists, are likely to orient quality of the products based on consumer want and need (Shewfelt, 1999). Consumers purchase produce based on appearance and textural quality, while repeat purchases are determined on organoleptic quality (i.e. taste, aroma). Consumers are also interested in the nutritional quality of fresh produce (Kader, 1988).

Texture as was already mentioned is an important parameter of physical quality not only because of the consumers preference to purchase firm fruit but also, because firmness indicates freshness; as a berry aging they loses turgidity throughout storage (Woodward, 1972). All of the studied cultivars maintained a storage life of 7-8 days throughout both production seasons that were evaluated. A strong correlation existed between the 6 day-neutral cultivars and strawberry firmness with an R^2 of 0.81. Strawberries produced from the 'San Andreas' cultivar were significantly firm with similar results from the following cultivars in descending order: 'Albion', 'Monterey', and 'Portola'. 'Seascape' and 'Evie 2' were significantly less firm berries. Throughout storage, the fruit from all cultivars was at its firmest ($P < 0.0001$) on day 2 of storage life and descended significantly ($P < 0.0001$) by day 7. Similarly in a separate study conducted in

Washington, Hoashi-Erdardt and Walters (2013) studied five of the six cultivars we investigated here and found that 'Monterey', 'Portola', and 'San Andreas' produced the firmest fruit. However, a South Korean study by Ruan et al. (2013a) observed 'Albion', 'Monterey', 'Portola', and 'San Andreas' in comparison to each other found that 'San Andreas', and 'Albion', produced the firmest fruit. Similar to our findings, Demchak et al., (2010) reports a negative texture softness of the fruit from the 'Evie 2' cultivar.

Color is a very important physical quality parameter as it contributes more to the consumer's quality standards than any other single factor (Kays, 1999). Color is the most apparent visual quality parameter for consumers (Kays, 1999). Although the weather factors were not controlled in our study, data shows its effect on the postharvest color quality of the day-neutral strawberries. All strawberry cultivars increased redness (a*) as maximum temperatures and average humidity increased, while decreasing redness (a*) and lightness (L*) with decreasing minimum temperatures. Strawberries tend to grow lighter with increasing average temperatures. Wang and Camp (2000), researched the effect of the differences between day and night temperature and observed that fruit lightness L* value decreased as the difference between day and night temperatures increased. This is in agreement with our study where cooler temperatures resulted in a darker, deep red berry. From our results, we can see that fruit redness is improved with cooler fruit temperatures, which may be expressed in a darker red skin color of berries, with lower a* and L* values. Strawberries grown from the 'San Andreas' was a bright red berry with the highest L* and a* values of the studied cultivars. Strawberry redness (a*) and lightness (L*) from the 'Monterey' and 'Albion' cultivars was inherently low. Throughout storage, all berries maintained their initial color throughout all eight harvests, and they become darker at the final day of storage. Previous studies show 'San Andreas' to be light in color. There is a lack of testing outside of California as well (Lantz et al., 2010b), although Ruan et al. (2013a), studied the colors of several day-neutral cultivars in South Korea and found 'San 'Andreas' to produce big, firm fruit with high a* values. Although the fruit from 'Albion' was dark and less-red, 'Albion' has shown optimum color and size in previous research (Demchak et al., 2010). 'Monterey' is reported to produce large, firm fruit, with little else reported on its color. A recent study assessing the physical and nutritional quality of four day-neutral cultivars including 'Albion' and 'Monterey', found that 'Monterey' had significantly low L* at 31.5, similar to our low findings of 33.1 (Samec et al., 2016).

Soluble solids content and titratable acidity are useful organoleptic qualities when determining strawberry flavor. Sweetness intensity is the primary factor contributing to overall liking for consumer (Schwieterman et al., 2014). In our study, 'Albion' and 'Monterey' contained the highest levels of soluble solids amongst all the cultivars at 7.77 and 7.65. Our findings are in agreement with Samec et al., (2016) who found that 'Albion' contained high SSC content ranging from 7.63 to 7.80. In addition, a large consumer study in Washington that determined from five of the six cultivars used in our study, that 'Albion' was rated highest in flavor in a series of consumer studies (Hoashi-Erdardt and Walters, 2013). Throughout storage, soluble solids content increased significantly with the greatest increase experienced by each cultivar day 4 in storage. Soluble solid content is positively correlated to water content (i.e. water loss percentage throughout storage). Hernández-Munoz et al. (2008) found as strawberries begin to lose moisture content, the soluble solid content is concentrated, thus increasing soluble solid content, which is why we observe an increase in SSC throughout storage. Both soluble solids and titratable acidity tended to decrease with rising maximum temperatures. All cultivars decreased SSC under maximum temperatures but 'Portola' and 'Evie 2' were largely affected by the extreme temperature decrease, with observed 36.6% SSC decrease and 32.8% SSC, respectively. A similar study done in high-elevation South Korea studied individual sugars and acids across a six month growing season within high tunnels among the day-neutral cultivars: 'Monterey', 'Portola', 'Albion', and 'San Andreas' (Ruan et al., 2013b). Likewise, they found interactive effects of cultivar and harvest time on the sugar content where spikes in temperature resulted in a dip in SSC. The authors suggest that high temperatures may result in increased respiration and consequently result in lower contents of sugars and soluble solids. They also speculate that a dip in SSC and %TA during late-season production occurs from less photosynthesis capacity due to decreased daylight hours. In addition, the SSC value varied from 6.7-8.3°Brix with the highest values for 'Albion' fruit and the lowest with 'Portola' fruit.

The total antioxidant content is an important nutritional quality parameter of fruit; in addition to its nutritional capacity and health promoting components, it is responsible for the bright red color of the berries. The antioxidant and phenolic compounds of strawberries are recognized as phytochemicals which display multiple health benefiting properties (Giampieri, 2015). The nutritional quality of the cultivars is based on the antioxidant capacity of the 6 day-neutral cultivars with the ORAC and FRAP analysis methods, accompanied by a measurement for total phenolic amount. Cultivar selection is oftentimes a great determinant of polyphenolic content in the antioxidant profile, with a slight effect based on ripening and growing conditions (Aaby et al., 2012; Tulipani et al., 2008). The strawberries from 'Evie 2' contained significantly high antioxidant levels by ORAC and total phenolic content ($P < 0.0001$ and $P < 0.001$, respectively). There was little difference observed among FRAP results. However, the fruit from the 'Portola' was significantly low according to the ORAC, FRAP, and total phenolic method ($P < 0.0001$, $P < 0.0001$, and $P < 0.0001$). Our FRAP measurements ranged from 1742µM TE/100g

FW to 2191μM TE/100g FW with 'Albion' and 'Monterey' containing the highest antioxidant levels, and was comparable with findings from the University of Guelph, Ontario with 18 genotypes, none of which were used in our study (Rekika et al., 2005). From our findings, 'Albion' and 'Monterey' were darker fruit with lower a* and L*, contained greater levels of SSC, along with the highest FRAP levels of the cultivars studied. This is in agreement with Wang et al. (1996), who also observed that darker fruit skin color largely contributes to overall antioxidant capacity.

Oxidative stress by free radicals is involved in the development of various diseases resulting in abundant present topics in the subject in food and agriculture research (Takashima et al., 2012). The literature provides variable results for acceptable antioxidant values by the ORAC method ranging from 1540μM TE/100g FW (Wang et al., 1996) to 6973μM TE/100g FW (Cao et al., 1993). Our findings were somewhere in the middle from 2290-4670μM TE/100g. Our total phenolic levels ranged from 146-242 (GAE/kg-FW). Which is comparable to total phenolic levels in 'Albion' and 'Monterey' from a recent report on day-neutral cultivars grown in Croatia, which ranged from 171-218 (GAE/kg-FW) (Samec et al., 2016). Although the findings for ORAC were not weather dependent, weather effects for both FRAP and total phenolic within the day-neutral cultivars. This indicates the strong influence of the degree of maturity, climatic factors, and postharvest storage on antioxidants (Lopes da Silva et al., 2007). Antioxidant measurements with FRAP and the total phenolic content increased with the increases in average temperature and average humidity. In the present study, a similar correlation among color analysis color a* and L*, also increased with increasing average temperature and humidity. Anthocyanin is the main antioxidant in strawberries and is responsible for the red color of strawberries (Timberlake and Bridle, 1982), and is assumed that the two would change sequentially throughout the production season.

Overall visual quality is an assessment of color, feel, and appearance and is a good signifier of many of the physical quality measurements assessed mechanically. ‘San Andreas’ strawberries had significantly higher ($P < 0.05$) visual quality in comparison to ‘Evie 2’ and ‘Seascape’, while ‘Monterey’, ‘Albion’, and ‘Portola’ had higher overall visual quality in comparison to ‘Seascape’ throughout storage. ‘San Andreas’ and ‘Monterey’ had the least moisture loss at 7.06% and 7.16% and ‘Seascape’ had the highest moisture loss throughout storage at 10.7%. Loss of turgidity was also seen in the firmness measurements of ‘Seascape’ and ‘Evie 2’ with lower firmness of all the day-neutral cultivars studied. In addition, ‘Seascape’ respired 28.6% more than the mean of the six cultivars ($P < 0.0001$). Throughout storage, the respiration rate was highest among all cultivars on day 7 ($P < 0.001$) and decreased significantly by day 8. The peak of respiration occurred on day 7 for all cultivars. We can see that the cultivars able to maintain their turgidity throughout storage and have little moisture loss, were also the cultivars respiring at lower rates and scoring high overall visual quality scores.

Conclusion

Our results show that spring-planted day-neutral cultivars grown in high tunnels in the central U.S can perform well regarding quality with appropriate cultivar selection. Through the assessment of the differences in the physical, chemical and phytochemical properties of six day-neutral strawberry cultivars, we can see various parameters of the cultivars at harvest, throughout storage, and/or in relation to the weather conditions. We were able to identify six day-neutral cultivars that maintained in marketable quality for a total of 7-8 days throughout storage. Based on the chemical and phytochemical parameters, we can determine that ‘Albion’ and ‘Monterey’ contained higher levels of SSC and phytochemical properties. However, based on the physical and storage quality parameters, ‘Albion’, ‘Monterey’, ‘Portola’, and ‘San Andreas’ all performed very similarly. As the maximum temperature increased, as did the color indexes L* and a*, while the SSC and %TA fell. We found that the berries with the highest soluble solids content were the darkest and corresponded to those cultivars with the lowest color index L* and a*. To our knowledge, this is the first report that examines the effect of the of evaporative cooling system within a high tunnel for day-neutral strawberry cultivars regarding the quality performance of the strawberries at harvest and during storage. Future controlled greenhouse studies are needed to address the effect of EC by eliminating outside variables. High Tunnel production provides a unique opportunity for growing day-neutral strawberries in the central U.S. With limited studies of the specific day-neutral strawberries grown within a high tunnel in the central U.S., growers may be unable to implement this production system. This data provides information for growers related to strawberry quality at harvest and during storage for six day-neutral cultivars growing under high tunnels with the implementation of evaporative cooling. Further trials are needed to identify the effect of weather and best management practices in the region to maintain high quality cultivars.

Table 4 - Effect of cultivar and weather on firmness (force (g)) of 6 day-neutral strawberry cultivars studied at harvest

Term[xz]	Scaled Estimate[y]	Prob>|t|
Intercept	435.26	<.0001*
Cultivar[Albion]	57.98	0.0032*
Cultivar[Evie 2]	-131.4	<.0001*
Cultivar[Monterey]	65.15	0.0008*
Cultivar[Portola]	59.96	0.0019*
Cultivar[San Andreas]	77.71	<.0001*
Cultivar[Seascape]	-129.4	<.0001*
Treatment[without EC]	-0.47	0.9554
Treatment[with EC]	0.47	0.9554
Max Temp. [t]	-81.74	0.0028*
Min Temp.[u]	69.93	0.5571
Avg. Temp.[v]	64.50	0.2001
Avg. Humidity[w]	-62.07	0.3526

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, weather conditions) displayed.
[t]Maximum temperature events experienced within two weeks prior to the eight harvests from 88.7°F-99.5°F.
[u]Minimum temperature events experienced within two weeks prior to the eight harvests from 33.4°F-68.4°F.
[v]Average temperature experienced within two weeks prior to the eight harvests from 70.1°F-81.5°F.
[w]Average humidity experienced within two weeks prior to the eight harvests from 70.02%-76.09%.

Table 5-Physical quality parameters of firmness (force (g)), color index (a*), and color index (L*) means of 6 day-neutral strawberry cultivars at harvest across both production seasons.

Cultivar[wxz]	Firmness(force (g))	Color (*a)	Color (L*)
Albion	492.80 a	34.00 cd	33.29 c
Evie 2	303.43 b	35.67 ab	35.94 ab
Monterey	499.90 a	33.86 d	33.10 c
Portola	494.80 a	35.19 bc	35.65 b
San Andreas	512.51 a	36.54 a	36.90 a
Seascape	305.34 b	35.82 ab	36.68 a

[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[z]Means separation within a column marked with the same letter do not differ ($P \leq 0.05$), Student t-test procedure.
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Table 6- Effect of cultivar, storage day, and evaporative cooling treatment on the firmness (force (g)) parameter throughout storage.

Term[xz]	Scaled Estimate[y]	Prob>|t|
Intercept	425.56	<.0001*
Cultivar[Albion]	36.97	0.0001*
Cultivar[Evie 2]	-132.3	<.0001*

Term[xz]	Scaled Estimate[y]	Prob>|t|
Cultivar[Monterey]	79.95	<.0001*
Cultivar[Portola]	44.88	<.0001*
Cultivar[San Andreas]	104.37	<.0001*
Cultivar[Seascape]	-133.8	<.0001*
Storage Day[0]	5.66	0.4460
Storage Day[2]	29.43	<.0001*
Storage Day[4]	-3.33	0.6533
Storage Day[7]	-31.75	<.0001*
Treatment[with EC]	-2.69	0.5382
Treatment[without EC]	2.69	0.5382
Cultivar[Portola]*Treatment[with EC]	-20.08	0.0385*
Cultivar[Portola]*Treatment[without EC]	20.08	0.0385*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, storage day, year) displayed
□ Final storage day dependent on Overall Visual Quality (Table 24)

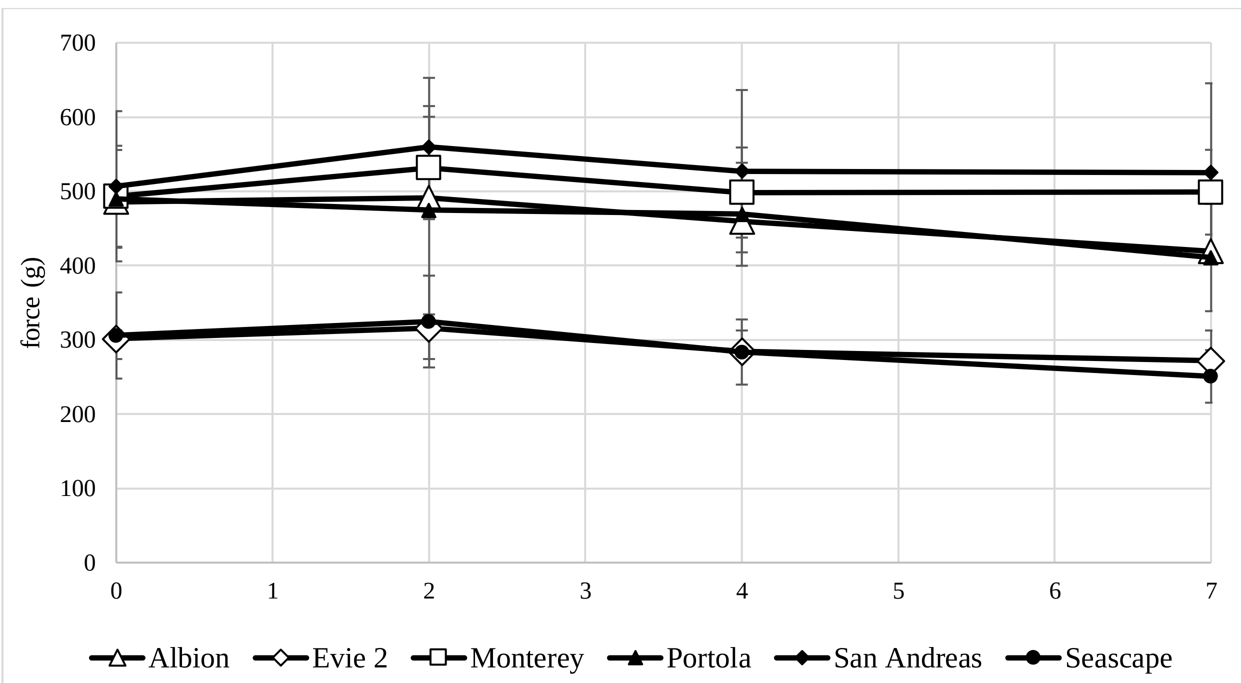


Figure 10 –Firmness (force (g)) of the of 6 day-neutral strawberry cultivars studied during storage.

90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Table 7 – Effect of cultivars and storage day on firmness (force (g)) of the 6 day-neutral strawberry cultivars studied.

Cultivar[wxz]	Storage Day			
	0	2	4	7
Albion	bc	bc	cd	d
Evie 2	ef	e	ef	ef
Monterey	bc	ab	bc	bc
Portola	bc	bc	cd	d
San Andreas	abc	a	ab	abc
Seascape	ef	e	ef	f

[z]Means separation within a column marked with the same letter do not differ ($P \leq 0.05$), Student t-test procedure.
[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

□ Final storage day dependent on Overall Visual Quality (Table 24)

Table 8 – Effect of cultivar, weather, and evaporative cooling treatment on color index (a*) of the 6 day-neutral strawberry cultivars studied at harvest.

Term [zx]	Scaled Estimate[y]	Prob>|t|
Intercept	35.17	<.0001*
Cultivar[Albion]	-1.14	0.0099*
Cultivar[Evie 2]	0.42	0.2969
Cultivar[Monterey]	-1.35	0.0016*
Cultivar[Portola]	-0.03	0.9316
Cultivar[San Andreas]	1.54	0.0015*
Cultivar[Seascape]	0.57	0.1628
Treatment[without EC]	0.24	0.2091
Treatment[with EC]	-0.24	0.2091
Max Temp.[t]	1.59	0.0154*
Min Temp.[u]	-6.02	0.0153*
Avg. Temp.[v]	1.59	0.1468
Avg. Humidity[w]	4.77	0.0034*
Year2014	-0.76	0.0010*
Year2015	0.76	0.0010*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, year, weather conditions) displayed.
[t]Maximum temperature events experienced within two weeks prior to the eight harvests from 88.7°F-99.5°F.
[u]Minimum temperature events experienced within two weeks prior to the eight harvests from 33.4°F-68.4°F.
[v]Average temperature experienced within two weeks prior to the eight harvests from 70.1°F-81.5°F.
[w]Average humidity experienced within two weeks prior to the eight harvests from 70.02%-76.09%.

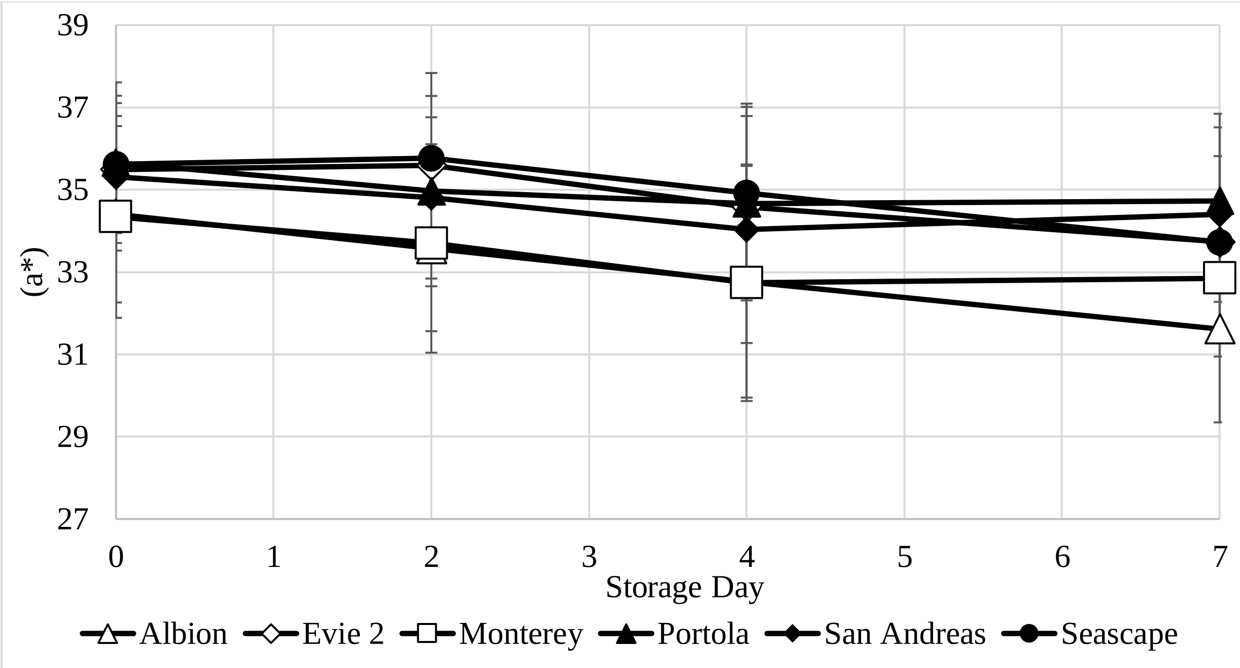


Figure 11- Physical quality parameter of color index (a*) throughout storage based on the effects of cultivar

90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Table 9 –Physical quality parameter of color index (a*) throughout storage based on the effects of cultivar, evaporative cooling treatment, and storage day.

Term[xz]	Scaled Estimate[y]	Prob>|t|
Intercept	34.481	<.0001*
Cultivar[Albion]	-1.542	<.0001*
Cultivar[Evie 2]	-0.262	0.4486
Cultivar[Evie2]	1.285	0.0088*
Cultivar[Monterey]	-1.010	0.0005*
Cultivar[Portola]	0.440	0.1293
Cultivar[San Andreas]	-0.005	0.9862
Cultivar[Seascape]	1.094	0.0004*
Treatment[without EC]	0.199	0.1446
Treatment[with EC]	-0.199	0.1446
Storage Day[0]	0.690	0.0029*
Storage Day[2]	0.531	0.0214*
Storage Day[4]	-0.219	0.3417
Storage Day[7]	-1.003	<.0001*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, storage day, year) displayed

☐ Final storage day dependent on Overall Visual Quality (Table 24)

Table 10- Physical quality parameter of color index (L*) at harvest of 6 day-neutral strawberry cultivars studied based on the effect of cultivar, evaporative cooling treatment, weather, and production year.

Term [zx]	Scaled Estimate [y]	Prob>|t|
Intercept	35.31	<.0001*
Cultivar[Albion]	-2.02	<.0001*
Cultivar[Evie 2]	0.77	0.0098*
Cultivar[Monterey]	-2.15	<.0001*
Cultivar[Portola]	0.48	0.0881
Cultivar[San Andreas]	1.56	<.0001*
Cultivar[Seascape]	1.37	<.0001*
Treatment[without EC]	-0.21	0.1284
Treatment[with EC]	0.21	0.1284
Max Temp.[t]	0.44	0.3378
Min Temp.[u]	5.56	0.0023*
Avg. Temp.[v]	-3.50	<.0001*
Avg. Humidity[w]	-2.82	0.0136*
Year2014	-0.39	0.0159*
Year2015	0.39	0.0159*
Cultivar[Albion]*(Min Temp.-56.0553)	-6.55	0.0121*
Cultivar[Seascape]*(Min Temp.-56.0553)	-9.49	0.0067*
Cultivar[Albion]*(Avg. Temp.-76.402)	3.63	0.0239*
Cultivar[Seascape]*(Avg. Temp.-76.402)	3.41	0.0403*
Cultivar[Albion]*(Avg. Humidity-73.4217)	4.21	0.0109*
Cultivar[Seascape]*(Avg. Humidity-73.4217)	6.42	0.0036*
Cultivar[San Andreas]*Year2014	1.54	0.0009*
Cultivar[San Andreas]*Year2015	-1.54	0.0009*
Cultivar[Seascape]*Year2014	-0.67	0.0339*
Cultivar[Seascape]*Year2015	0.67	0.0339*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, year, weather conditions) displayed.
[t]Maximum temperature events experienced within two weeks prior to the eight harvests from 88.7°F-99.5°F.
[u]Minimum temperature events experienced within two weeks prior to the eight harvests from 33.4°F-68.4°F.
[v]Average temperature experienced within two weeks prior to the eight harvests from 70.1°F-81.5°F.
[w]Average humidity experienced within two weeks prior to the eight harvests from 70.02%-76.09%.

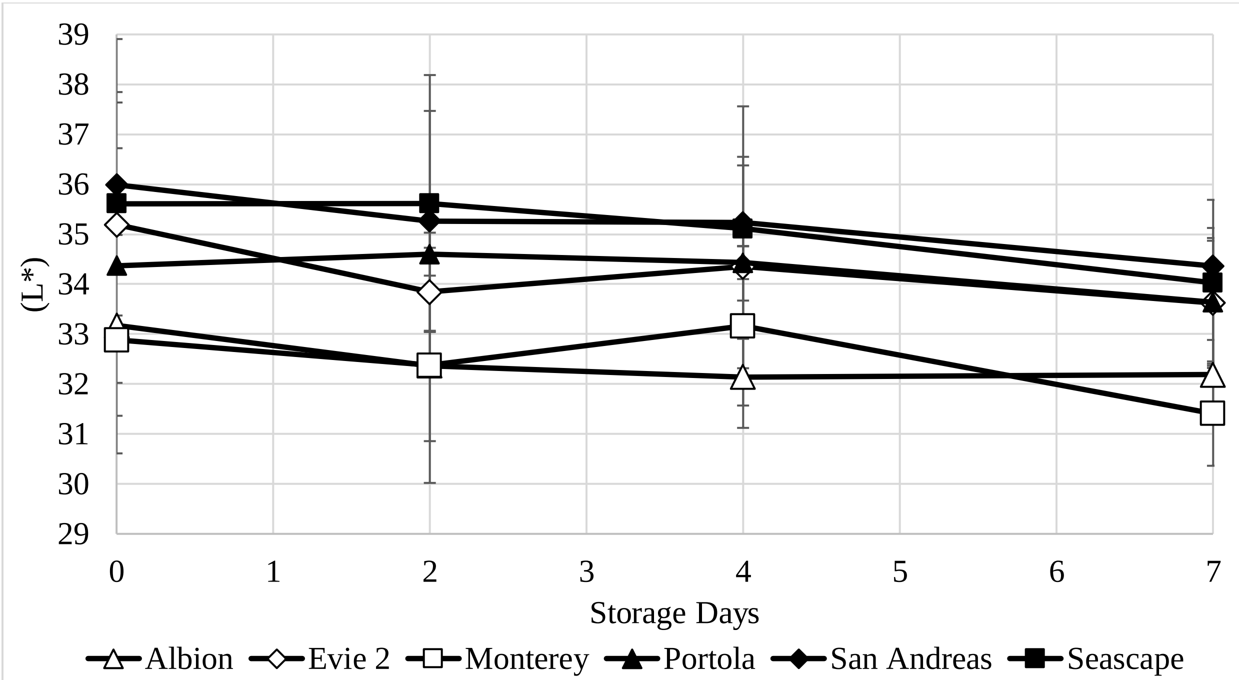


Figure 12- Effect of cultivar on the color index (L*) throughout storage.

90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Table 11 – Effect of cultivar, storage day, and evaporative cooling treatment factors on the color index (L*) throughout storage.

Term[zx]	**Scaled Estimate**[y]	**Prob>|t|**
Intercept	34.76	<.0001*
Cultivar[Albion]	-1.68	<.0001*
Cultivar[Evie 2]	0.39	0.0565
Cultivar[Monterey]	-2.07	<.0001*
Cultivar[Portola]	0.60	0.0028*
Cultivar[San Andreas]	1.49	<.0001*
Cultivar[Seascape]	1.27	<.0001*
Storage Day[0]	0.53	0.0007*
Storage Day[2]	0.42	0.0071*
Storage Day[4]	-0.06	0.7140
Storage Day[7]	-0.89	<.0001*
Treatment[without EC]	-0.43	<.0001*
Treatment[with EC]	0.43	<.0001*
Cultivar[Monterey]*Treatment[without EC]	0.45	0.0265*
Cultivar[Monterey]*Treatment[with EC]	-0.45	0.0265*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, storage day, year) displayed

☐ Final storage day dependent on Overall Visual Quality (Table 24)

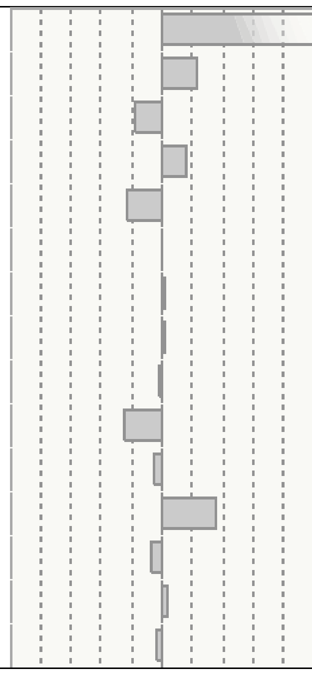
Table 12- Organoleptic quality parameter means of soluble solids content (SSC), Titratable Acidity (%TA), and the ratio of SSC/%TA at harvest of 6 day-neutral strawberry varieties studied across two production years.

Cultivar[wxz]	SSC(°Brix)	Titratable Acidity (%TA)	SSC/%TA
Albion	7.77 a	0.934 ab	8.32
Evie 2	6.46 bc	0.877 bc	7.36
Monterey	7.65 a	0.831 cd	9.21
Portola	6.33 c	0.811 d	7.81
San Andreas	7.12 ab	0.842 cd	8.46
Seascape	7.19 a	0.927 a	7.76

[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[z]Means separation within a column marked with the same letter do not differ ($P \leq 0.05$), Student t-test procedure.
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Table 13- Physical quality parameter of SSC (°Brix) at harvest of 6 day-neutral strawberry cultivars studied based on the effect of cultivar, evaporative cooling treatment, weather, and production year.

Term [zx]	Scaled Estimate[y]	Prob>|t|
Intercept	7.091	<.0001*
Cultivar[Albion]	0.756	0.0036*
Cultivar[Evie 2]	-0.601	0.0147*
Cultivar[Monterey]	0.542	0.0269*
Cultivar[Portola]	-0.742	0.0031*
Cultivar[San Andreas]	0.002	0.9945
Cultivar[Seascape]	0.044	0.8547
Treatment[without EC]	0.072	0.5223
Treatment[with EC]	-0.072	0.5223
Max Temp.[t]	-0.842	0.0170*
Min Temp.[u]	-0.183	0.8786
Av. Temp.[v]	1.199	0.0597
Av. Humidity[w]	-0.252	0.7306
Year[2014]	0.092	0.4312
Year[2015]	-0.092	0.4312



[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, year, weather conditions) displayed.
[t]Maximum temperature events experienced within two weeks prior to the eight harvests from 88.7°F-99.5°F.
[u]Minimum temperature events experienced within two weeks prior to the eight harvests from 33.4°F-68.4°F.
[v]Average temperature experienced within two weeks prior to the eight harvests from 70.1°F-81.5°F.
[w]Average humidity experienced within two weeks prior to the eight harvests from 70.02%-76.09%.

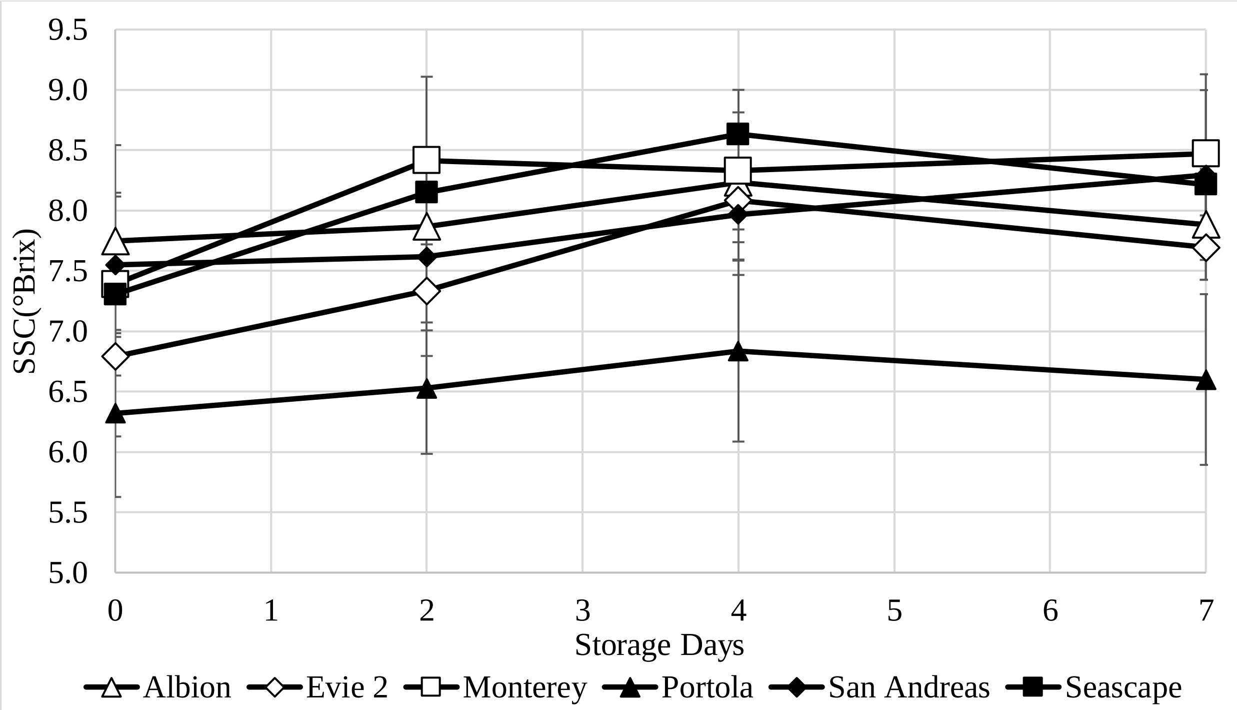


Figure 13- Effect of cultivar on the soluble solids content (°Brix) parameter throughout storage.

90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Table 14- Effect of cultivar, storage day, and evaporative cooling treatment factors on the soluble solids content (°Brix) parameter throughout storage.

Term [zx]	Scaled Estimate [y]		Prob>|t|
Intercept	7.484		<.0001*
Cultivar[Albion]	0.096		0.3894
Cultivar[Evie 2]	0.090		0.4255
Cultivar[Monterey]	0.083		0.4583
Cultivar[Portola]	-0.553		<.0001*
Cultivar[San Andreas]	-0.045		0.6947
Cultivar[Seascape]	0.328		0.0065*
Storage Day[0]	-0.365		<.0001*
Storage Day[2]	-0.104		0.2303
Storage Day[4]	0.274		0.0016*
Storage Day[7]	0.194		0.0280*
Treatment[1]	-0.084		0.1001
Treatment[2]	0.084		0.1001
Year[2014]	-0.203		<.0001*

Term [zx]	Scaled Estimate [y]	Prob>|t|
Year[2014]	0.203	<.0001*
Cultivar[Albion]*Year[2014]	-0.153	0.1652
Cultivar[Albion]*Year[2014]	0.153	0.1652
Cultivar[Evie 2]*Year[2014]	0.306	0.0067*
Cultivar[Evie 2]*Year[2014]	-0.306	0.0067*
Cultivar[Monterey]*Year[2014]	-0.388	0.0005*
Cultivar[Monterey]*Year[2014]	0.388	0.0005*
Cultivar[Portola]*Year[2014]	0.565	<.0001*
Cultivar[Portola]*Year[2014]	-0.565	<.0001*
Cultivar[San Andreas]*Year[2014]	-0.229	0.0438*
Cultivar[San Andreas]*Year[2014]	0.229	0.0438*
Cultivar[Seascape]*Year[2014]	-0.101	0.3870
Cultivar[Seascape]*Year[2014]	0.101	0.3870

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, storage day, year) displayed
□ Final storage day dependent on Overall Visual Quality (Table 24)

Table 15 – Organoleptic quality parameter titratable acidity (%TA) at harvest was based on the effect of cultivar, evaporative cooling treatment, weather, and production year.

Term [zx]	Scaled Estimate [y]	Prob>|t|
Intercept	0.88	<.0001*
Cultivar[Albion]	0.08	0.0001*
Cultivar[Evie 2]	0.00	0.9496
Cultivar[Monterey]	-0.04	0.0177*
Cultivar[Portola]	-0.06	0.0009*
Cultivar[San Andreas]	-0.02	0.2021
Cultivar[Seascape]	0.06	0.0053*
Treatment[without EC]	0.02	0.0667
Treatment[with EC]	-0.02	0.0667
Max Temp. [t]	-0.12	0.0451*
Min Temp. [u]	-0.11	0.3969
Avg. Temp. [v]	0.05	0.5690
Avg. Humidity [w]	0.06	0.2800
Year[2014]	0.05	0.1830
Year[2015]	-0.05	0.1830

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, year, weather conditions) displayed.
[t]Maximum temperature events experienced within two weeks prior to the eight harvests from 88.7°F-99.5°F.
[u]Minimum temperature events experienced within two weeks prior to the eight harvests from 33.4°F-68.4°F.
[v]Average temperature experienced within two weeks prior to the eight harvests from 70.1°F-81.5°F.

[w]Average humidity experienced within two weeks prior to the eight harvests from 70.02%-76.09%.

Table 16 – Effect of cultivar, storage day, and evaporative cooling treatment factors on the titratable acidity (%TA) parameter throughout storage.

Term [zx]	Scaled Estimate [y]	Prob>|t|
Intercept	0.89	<.0001*
Cultivar[Albion]	0.05	0.0002*
Cultivar[Evie 2]	0.01	0.6872
Cultivar[Monterey]	-0.02	0.2499
Cultivar[Portola]	-0.07	<.0001*
Cultivar[San Andreas]	-0.02	0.1735
Cultivar[Seascape]	0.05	0.0014*
Storage Day[0]	-0.00	0.7179
Storage Day[2]	-0.00	0.9760
Storage Day[4]	0.01	0.4651
Storage Day[7]	-0.00	0.7414
Treatment[without EC]	0.01	0.0319*
Treatment[with EC]	-0.01	0.0319*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, storage day, year) displayed
☐ Final storage day dependent on Overall Visual Quality (Table 24)

Table 17 – The antioxidant capacity of 6 day-neutral strawberry cultivars studied using ORAC (μM TE/100g FW), FRAP (μM TE/100g FW), and Total Phenolic method (GAE/kg-FW).

Cultivar [wxz]	ORAC (μM TE/100g FW)	FRAP (μM TE/100g FW)	Total Phenolic (GAE/kg FW)
Albion	3645.43 c	2112.92 a	228.27 ab
Evie 2	4667.94 a	2057.88 a	242.73 a
Monterey	3799.74 bc	2191.45 a	236.78 ab
Portola	2290.47 d	1742.38 ab	146.95 c
San Andreas	3665.22 bc	1743.22 a	219.80 ab
Seascape	4339.50 ab	1758.49 a	215.77 b

[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[z]Means separation within a column marked with the same letter do not differ ($P \leq 0.05$), Student t-test procedure.
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Table 18 – Effect of weather, evaporative cooling treatment, and production year on the ORAC (μM TE/100g FW) capacity of 6 day-neutral strawberry cultivars studied.

Term [zx]	Scaled Estimate [y]	Prob>|t|
Intercept	3850.0	<.0001*
Cultivar[Albion]	-128.9	0.4738
Cultivar[Evie 2]	957.36	<.0001*
Cultivar[Monterey]	70.61	0.7011
Cultivar[Portola]	-1450	<.0001*

Term [z,x]	Scaled Estimate [y]	Prob>|t|
Cultivar[San Andreas]	62.43	0.7630
Cultivar[Seascape]	488.74	0.0110*
Treatment[without EC]	124.87	0.1659
Treatment[with EC]	-124.9	0.1659
Max Temp.[t]	538.01	0.1305
Min Temp.[u]	-324.9	0.7958
Avg. Temp.[v]	-207.3	0.7239
Avg. Humidity[w]	740.35	0.3546
Year[2014]	571.98	<.0001*
Year[2015]	-572.0	<.0001*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, year, weather conditions) displayed.
[t]Maximum temperature events experienced within two weeks prior to the eight harvests from 88.7°F-99.5°F.
[u]Minimum temperature events experienced within two weeks prior to the eight harvests from 33.4°F-68.4°F.
[v]Average temperature experienced within two weeks prior to the eight harvests from 70.1°F-81.5°F.
[w]Average humidity experienced within two weeks prior to the eight harvests from 70.02%-76.09%.

Table 19 – The effect of weather, production year, and evaporative cooling treatment on antioxidant capacity of 6 day-neutral strawberry cultivars studied at harvest using FRAP (μM TE/100g FW).

Term [z,x]	Scaled Estimate [y]	Prob>|t|
Intercept	1994.0063	<.0001*
Cultivar[Albion]	27.191594	0.7724
Cultivar[Evie 2]	187.45999	0.0492*
Cultivar[Monterey]	243.41092	0.0101*
Cultivar[Portola]	-753.744	<.0001*
Cultivar[San Andreas]	177.57209	0.0718
Cultivar[Seascape]	118.10941	0.2243
Treatment[without EC]	6.7103787	0.8816
Treatment[with EC]	-6.710379	0.8816
Max Temp.[t]	-707.4972	<.0001*
Min Temp.[u]	-920.209	0.0779
Av. Temp.[v]	1052.1488	<.0001*
Av. Humidity[w]	771.59023	0.0167*
Year[2014]	634.08216	<.0001*
Year[2015]	-634.0822	<.0001*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, year, weather conditions) displayed.
[t]Maximum temperature events experienced within two weeks prior to the eight harvests from 88.7°F-99.5°F.
[u]Minimum temperature events experienced within two weeks prior to the eight harvests from 33.4°F-68.4°F.
[v]Average temperature experienced within two weeks prior to the eight harvests from 70.1°F-81.5°F.
[w]Average humidity experienced within two weeks prior to the eight harvests from 70.02%-76.09%.

Table 20 – The effect of weather, production year, and evaporative cooling treatment on total phenolic (GAE/kg FW) amounts of 6 day-neutral strawberry cultivars studied at harvest.

Term[x z]	Scaled Estimate[y]	Prob>|t|
Intercept	213	<.0001*
Cultivar[Albion]	13.2	0.0496*
Cultivar[Evie 2]	24.2	0.0004*
Cultivar[Monterey]	21.7	0.0013*
Cultivar[Portola]	-68	<.0001*
Cultivar[San Andreas]	8.13	0.2394
Cultivar[Seascape]	0.97	0.8885
Treatment[without EC]	13.6	<.0001*
Treatment[with EC]	-14	<.0001*
Max Temp.[t]	0.16	0.9872
Min Temp.[u]	-215	<.0001*
Avg. Temp.[v]	135	<.0001*
Avg. Humidity[w]	139	<.0001*
Year[2014]	-4.6	0.1726
Year[2015]	4.60	0.1726

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, year, weather conditions) displayed.
[t]Maximum temperature events experienced within two weeks prior to the eight harvests from 88.7°F-99.5°F.
[u]Minimum temperature events experienced within two weeks prior to the eight harvests from 33.4°F-68.4°F.
[v]Average temperature experienced within two weeks prior to the eight harvests from 70.1°F-81.5°F.
[w]Average humidity experienced within two weeks prior to the eight harvests from 70.02%-76.09%.

Table 21 –Moisture Loss (%), Respiration (mLCO_2/kg-h), and Overall Visual Quality (AUC) throughout storage.

Cultivar	Moisture Loss (%)	Respiration Rate (mLCO_2/kg-h)	Overall Visual Quality (AUC)
Albion	7.94 ab	12.60 c	24.36 ab
Evie 2	9.63 ab	14.30 bc	21.75 bc
Monterey	7.16 b	15.42 b	24.52 ab
Portola	7.73 ab	13.36 bc	24.36 abc
San Andreas	7.12 b	14.77 bc	24.86 a
Seascape	10.65 a	21.42 a	21.89 c

[w]90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[z]Means separation within a column marked with the same letter do not differ ($P \leq 0.05$), Student t-test procedure.
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Table 22 –Moisture loss (%) of 6 day-neutral strawberry cultivars studied based on the effect of cultivar, evaporative cooling treatment, and production year.

Term[zx]	Scaled Estimate[y]	Prob>|t|
Intercept	8.397	<.0001*

Term [zx]	Scaled Estimate [y]	Prob>|t|
Cultivar[Albion]	-0.456	0.5378
Cultivar[Evie 2]	1.234	0.0980
Cultivar[Monterey]	-1.216	0.1029
Cultivar[Portola]	-0.597	0.4200
Cultivar[San Andreas]	-1.260	0.0915
Cultivar[Seascape]	2.294	0.0027*
Treatment[without EC]	-0.195	0.5549
Treatment[with EC]	0.195	0.5549
Year[2014]	1.617	<.0001*
Year[2015]	-1.617	<.0001*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, year) displayed.

Table 23 –Respiration rate (mLCO_2/kg-h) of 6 day-neutral strawberry cultivars studied throughout storage based on the effect of cultivar, evaporative cooling treatment, and storage day.

Term	Scaled Estimate	Prob>|t|
Intercept	15.31	<.0001*
Cultivar[Albion]	-2.71	<.0001*
Cultivar[Evie 2]	-1.01	0.1094
Cultivar[Monterey]	0.11	0.8643
Cultivar[Portola]	-1.96	0.0021*
Cultivar[San Andreas]	-0.54	0.3952
Cultivar[Seascape]	6.11	<.0001*
Treatment[with EC]	0.38	0.1710
Treatment[without EC]	-0.38	0.1710
Storage Day[0]	-1.79	0.0102*
Storage Day[1]	-2.13	0.0023*
Storage Day[2]	1.11	0.1116
Storage Day[3]	-0.78	0.2627
Storage Day[4]	0.36	0.6342
Storage Day[5]	0.66	0.4336
Storage Day[6]	-0.55	0.4323
Storage Day[7]	3.12	0.0003*

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, storage day, year) displayed

☐ Final storage day dependent on Overall Visual Quality (Table 24)

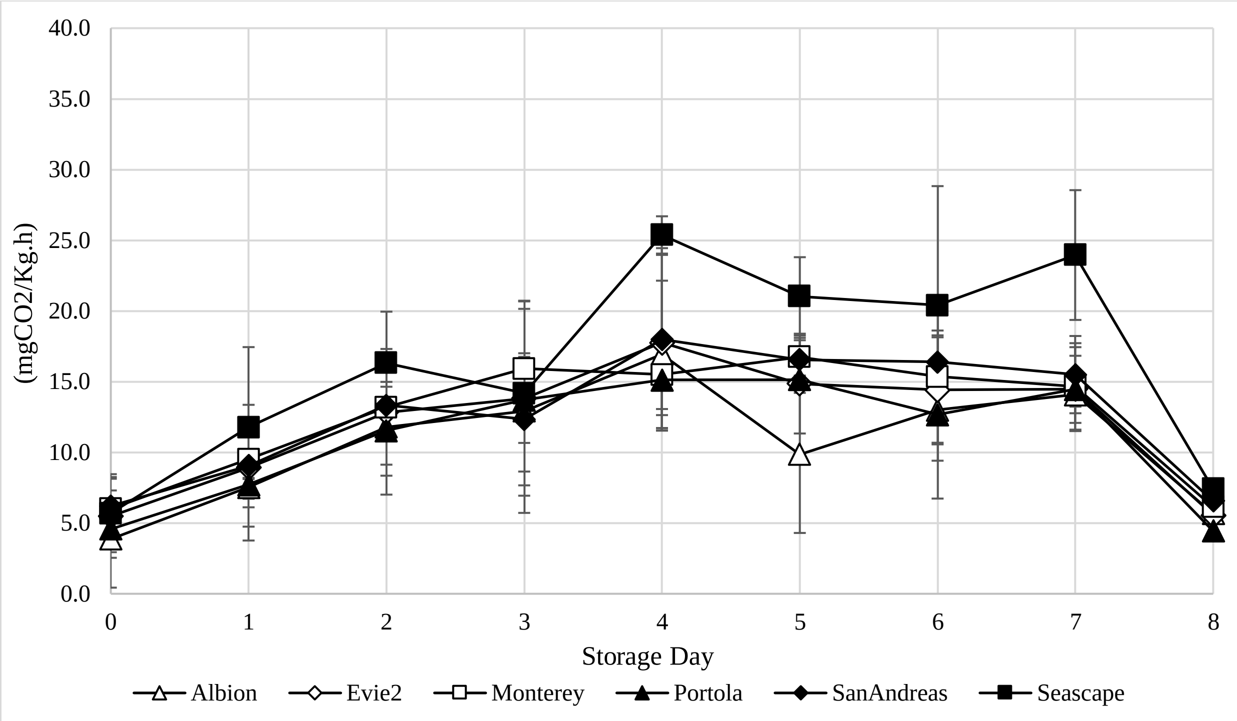


Figure 14 –Respiration rate (mLCO$_2$/kg-h) of 6 day-neutral strawberry cultivars studied throughout storage during growing season 2014

90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

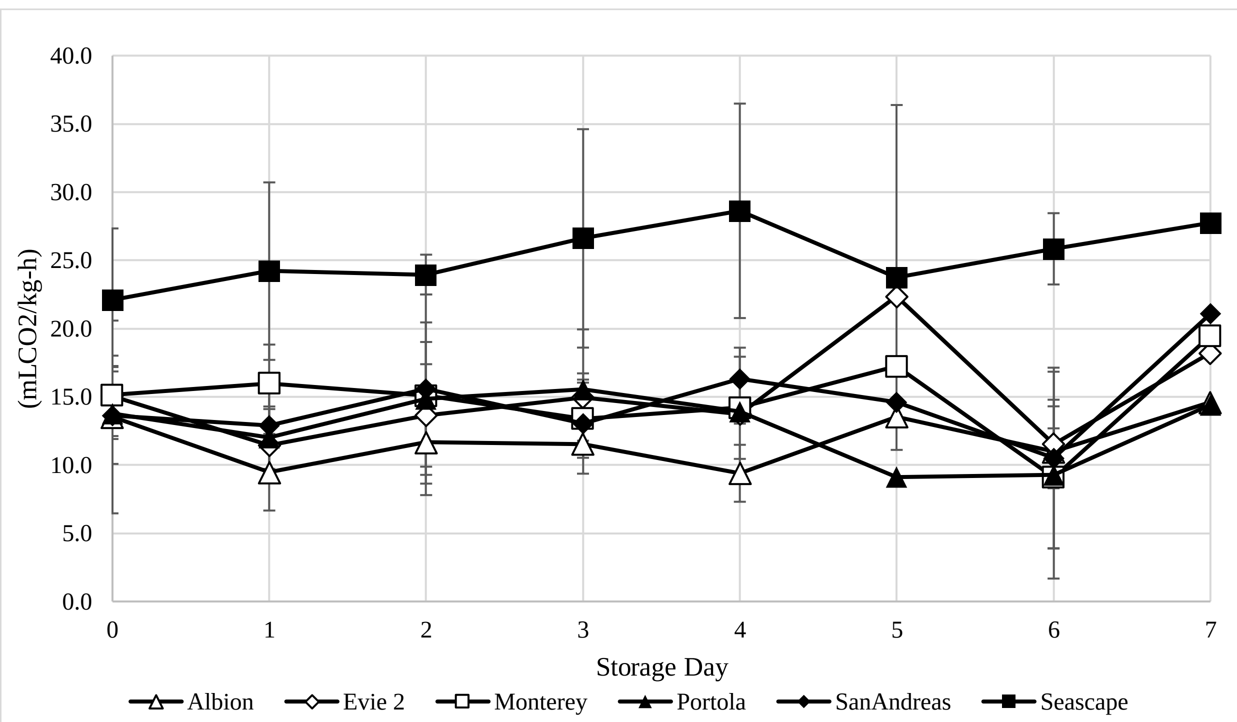


Figure 15- Respiration rate ($mLCO_2$/kg-h) of 6 day-neutral strawberry cultivars studied throughout storage during growing season 2015

90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.

Table 24 –Overall visual quality parameter (AUC) based on effects of cultivar, evaporative cooling treatment, and production year.

Term [zx]	Scaled Estimate [y]	Prob>|t|
Intercept	23.62	<.0001*
Cultivar[Albion]	0.86	0.1848
Cultivar[Evie 2]	-1.89	0.0043*
Cultivar[Monterey]	0.89	0.1677
Cultivar[Portola]	0.72	0.2624
Cultivar[San Andreas]	1.23	0.0587
Cultivar[Seascape]	-1.81	0.0060*
Treatment[with EC]	-0.04	0.8768
Treatment[without EC]	0.04	0.8768
Year[2014]	0.38	0.1814
Year[2015]	-0.38	0.1814

[z]90-100% mature fruit harvested four times in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
[x]Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
[y]Regressions estimates, only significant interactions between factors (cultivar, treatment, year) displayed.

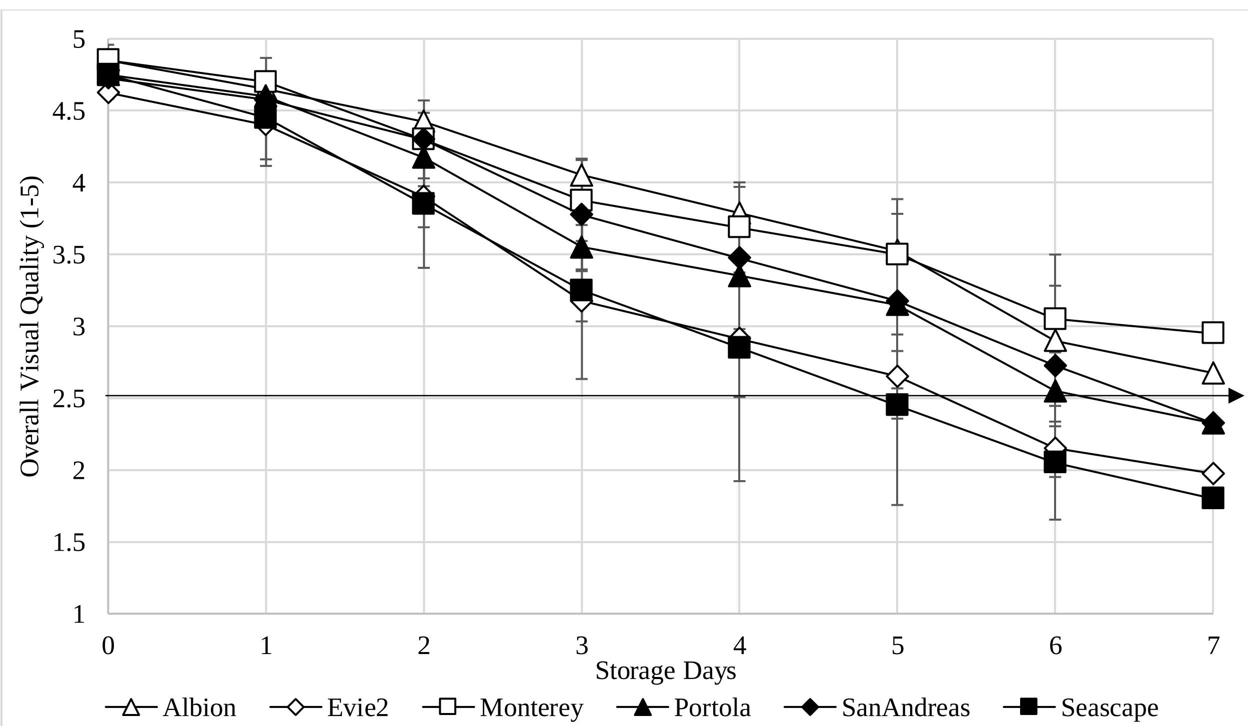


Figure 16- Overall visual quality (AUC) scores of 6 day-neutral cultivars throughout their storage life.

90-100% mature fruit harvested once or twice weekly in 2014 (10 May 2014- 6 Oct. 2014) and 2015 (31 May 2015- 6 Oct. 2015).
Experimental design as described in fig. 1 in split-plot design with four replications. Main plot treatments were with and without evaporative cooling and sub-plots were cultivars.
When 30% of the sample set (n=20) scored below 2.5, the cultivar was considered unmarketable.

Bibliography

Aaby, K., Mazur, S., Arnfinn, N., & Grete, S. (2012). Phenolic compounds in strawberry (*Fragaria ananassa* Duch.) fruits: Composition in 27 cultivars and changes during ripening. *Food Chemistry*, 132, 86–97.

Abate, G. (2008). Local food economies: driving forces, challenges, and future prospects. *Journal of Hunger & Environmental Nutrition*, 3, 384:399.

Abbott, J. A., Lu, R., Upchurch, B. L. & Stroshine, R. L. (1997). Technologies for nondestructive quality evaluation of fruits and vegetables, in horticultural Reviews, Volume 20 (ed J. Janick), John Wiley & Sons, Inc., Oxford, UK. doi: 10.1002/9780470650646.ch1

Ames, B.M., Shigena, M.K. & Hagen, T.M. (1993). Oxidants, antioxidants, and the degenerative diseases of aging. *Proc. Natl. Acad. Sci*. U.S.A., 90, 7915-7922.

Archbold, D. D. (1988). Abscisic acid facilitates sucrose import by strawberry fruit explants and cortex disks in vitro. *HortScience (USA)*.

Ayala-Zavala, J. F., Wang, S. Y., Wang, C. Y., & González-Aguilar, G. A. (2004). Effect of storage temperatures on antioxidant capacity and aroma compounds in strawberry fruit. *LWT-Food Science and Technology*, *37*(7), 687-695.

Bakker, J., Bridle, P., Timberlake, C. F., & Arnold, G. M. (1986). The colours, pigment and phenol contents of young port wines: Efiects of cultivar, season and site. *Vitis*, *25*, 40-52.

Bakker, J. Bridle, P., & Bellworthy, S.J. (1994). Strawberry juice color – A study of the quantitative and qualitative pigment composition of juices from 39 genotypes. *Journal of the Science of Food and Agriculture,* 64, 31–37.

Ballington, J. R., Poling, B.E., and Olive, K. (2008). Day-neutral strawberry production for season extension in the midsouth. HortScience, 43(7): 1982-1986.

Becker, B.R. & Fricke, B.A. (1996). Transpiration and respiration of fruits and vegetables. University of Missouri -Kansas City, Kansas City, MO.

Belasco, E., Chen, C., Ponnaluru, S. S., Galinato, S. P., & Marsh, T. L. (2011). An Assessment of the Interaction between High Tunnels and Crop Insurance for Specialty Crop Producers. In *2011 Annual Meeting, July 24-26, 2011, Pittsburgh, Pennsylvania* (No. 103896). Agricultural and Applied Economics Association.

Belasco, E., Galinato, S., Marsh, T., Miles, C., & Wallace, R. (2013). High tunnel are my crop insurance: an assessment of risk management tools for small-scale specialty crop producers. Agriculture and Resource Economics Review, 42 (2) 403-418.

Bellows, A.C., Brown, K., & Smit, J. (2003). Health Benefits of Urban Agriculture. Community Food Security Coalition's North America Urban Agriculture Committee.

Benzie, I. F. F., & Strain, J. J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of 'antioxidant power': The FRAP assay. Annals of Biochemistry, 239, 70–76.

Black, B.L., Enns, J.M. & Hokanson, S.C. (2002). A comparison of temperate-climate strawberry production systems using eastern genotypes. HortTechnology 12:670-675.

Black, B., Drost, D., & Ward, R. (2010). High value crop rotations for Utah high tunnels. Utah State University. SARE SW07-035.

Blomgren, T. & Frisch, T. (2007). High tunnels: Using low-cost technology to increase yields, improve quality and extend the season. University of Vermont Center of Sustainable Agriculture, Burlington, VT. Retrieved from https://www.uvm.edu/~susagctr/resources/HighTunnels.pdf

Brennan, T. & Frenkel, C. (1977). Involvement of hydrogen peroxide in the regulation of senescence in pear. Plant Physiol. 59:411-416.

Hamm, M. W. (2008). Linking sustainable agriculture and public health: opportunities for realizing multiple goals. *Journal of Hunger & Environmental Nutrition*, *3*(2-3), 169-185.

Carey, E.E., Jett, L., Lamont, W.J. Jr., Nennich, T.T., Orzolek, M.D., Williams, K.A. (2009). Horticultural crop production in high tunnels in the United States: A snapshot. HortTechnology **19**:37–43.

Carey, E., Kelly, K., Hendrickson, M., Nagengast, D., Quinn, J., Volland, C., & Kumar, L. (2006). The growing growers training program: An apprenticeship program for market gardeners serving Kansas city. *HortTechnology*, *16*(3), 439-443.

Cavalieri, R.P. (1999). Fresh fruits and vegetable: quality and food safety, Postharvest boil. Technol. 15: 195-340.

Caner, C., Aday, M., Demir, M. (2008). Extending the quality of fresh strawberries by equilibrium modified atmosphere packaging. European Food Research and Technology 227, 1575–1583.

Cao, G., Alessio, H. M., & Cutler, R. G. (1993). Oxygen-radical absorbance capacity assay for antioxidants. *Free radical biology and medicine*, *14*(3), 303-311.

Connor, A. M., Luby, J. J., Tong, C. B., Finn, C. E., & Hancock, J. F. (2002). Genotypic and environmental variation in antioxidant activity, total phenolic content, and anthocyanin content among blueberry cultivars. *Journal of the American Society for Horticultural Science*, *127*(1), 89-97.

Chite, R. M. (2014). The 2014 farm bill (PL 113-79): Summary and side-by-side. *Congressional Research Service*, 7-5700.

Day-Farnsworth, L., et al. (2009). Scaling up: meeting the demand for local food, University of Wisconsin-Extension Ag. Innovation Center and UW-Madison Center for Integrated Agricultural Systems, Madison, WI.

Dara. S. K. (2012). Salt injury in strawberries. UCCE eNewsletter, Strawberries and Vegetables. http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=6820

Dara, S. K. (2016). Micro-Sprinklers in Strawberry Production. University of California Cooperative Extension. CAPCA Adviser, 38-41.

Darby, K., Batte, M. T., Ernst, S., & Roe, B. (2008). Decomposing local: a conjoint analysis of locally produced foods. *American Journal of Agricultural Economics*, *90*(2), 476-486.

Darrow, G. M. (1936). Interrelation of temperature and photoperiodism in the production of fruit-buds and runners in the strawberry. In *Proc. Amer. Soc. Hort. Sci* (Vol. 34, No. 3607, p. 363).

Demchak, K. (2009). Small fruit production in high tunnels. HortTechnology 19:44-49.

Demchak, K., Harper, J.K., Kime, L.F., and Lantz, W. (2010). Agricultural Alternatives: Strawberry Production. Penn State Extension. The Pennsylvania State University, Ag. Communication and marketing, University Park, PA.

Donoso, T. P. S. (2009). *Effects of High Tunnel Production on Florida Strawberry Growth, Yield and Postharvest Quality* (Doctoral dissertation, University of Florida).

Evans, R. G. (1993). "Overtree evaporative cooling system design and operation for apples in the PNW," The Good Fruit Grower, 44 (11) 23-27.

Evans, R. G. (2004). "Modeling the Energy Balance of Apples Under Evaporative Cooling," Transactions of American Society of Agricultural Engineers, 47 (4) 1029- 1037.

Feenstra, Gail. (1997). Local Food Systems and Sustainable Communities. American Journal of Alternative Agriculture, 12(1) 28-36.

Fenton, V. (2010). Day-neutral matted row, field and high tunnel plasticulture strawberry management systems in *2010 Fruit and Vegetable Research Report*. Department of Horticulture University of Kentucky, Lexington, KY. p. 12.

Fischer, M., Hamm, M., Pirog, R., Fisk, J., Farbman, J., and Kiraly, S. (2013). Findings of the 2013 National Food Hub Survey. Michigan State University Center of Regional Food

Systems and The Wallace Center at Winrock International. http://foodsystems.msu.edu/activities/food-hub-survey.

Food Marketing Institute (FMI) (2014). U.S. Grocery Shopper Trends, Food Marketing Institute: Arlington, VA.

Gaytan, M. (2003, August). Globalizing the local: Slow food and the collective imaginary. In *annual meeting of the American Sociological Association, Atlanta, GA*.

Gündüz, K., & Özdemir, E. (2014). The effects of genotype and growing conditions on antioxidant capacity, phenolic compounds, organic acid and individual sugars of strawberry. *Food chemistry*, *155*, 298-303.

Gustavsson, J., Cederberg, C., Sonesson, U., Van Otterdijk, R., & Meybeck, A. (2011). Global food losses and food waste. *Food and Agriculture Organization of the United Nations, Rom*.

Galinato, S., and Walters, T. (2012). 2011 Cost Estimates of Producing Strawberries in High Tunnel in Western Washington. *Washington State University Extension Publication* FS093E. http://cru.cahe.wsu.edu/CEPublications/FS093E/FS093E.pdf.

Giampieri, F., Forbes-Hernandez, T. Y., Gasparrini, M., Alvarez-Suarez, J. M., Afrin, S., Bompadre, S., ... & Battino, M. (2015). Strawberry as a health promoter: an evidence based review. *Food & function*, *6*(5), 1386-1398.

Gregoire, M.B., Arendt, S.W., Strohbehn, C.H. (2005). Iowa Producers' perceived benefits and obstacles in marketing to local restaurants and institutional foodservice operations. Journal of Extension, (43). http://www.joe.org/joe/2005february/rb1.php.

Grubinger, V. (2015). High tunnels and other season extension techniques. Topic Room Series. Sustainable Agriculture Research and Education, College Park, MD. Retrieved from www.SARE.org/season-extension

Guptill, A. and Wilkins, J.L. (2002). Buying into the food system: trends in food retailing in the U.S. and implications for local foods. Agriculture and Human values, (19) 39-51.

Harris, L. & Mitcham, E. (2007). Strawberries: Safe methods to store, preserve, and enjoy In ANR Catalog. University of California. *Agriculture and Natural Resources*, 15.

Häkkinen, S., Heinonen, M., Kärenlampi, S., Mykkänen, H., Ruuskanen, J., & Törrönen, R. (1999). Screening of selected flavonoids and phenolic acids in 19 berries. *Food Research International*, *32*(5), 345-353.

Heidenreich, C., Pritts, M., Kelly, M.J., and Demchak, K. (2007). High Tunnel Raspberries and Blackberries. Deparment of Horticulture. N. 47. Cornell University, Ithaca, NY.

Hellman, E.W., Travis, J.D., 1988. Growth inhibition of strawberry at high temperatures. Adv. Strawberry Prod. 7, 36–38.

Hernández-Herrero, J.A. and Frutos, M.J. (2014). Colour and antioxidant capacity stability in grape, strawberry and plum peel model juices at different pH's and temperatures. J. of Food Chemistry, 154, 199-204

Hernández-Munoz, P., Almenar, E., Valle, V. Del, Velez, D., and Rafael Gavara. (2008). Effect of chitosan coating combined with postharvest calcium treatment on strawberry (*Fragaria* x *ananassa*) quality during refrigerated storage. Food Chemistry, 110, 428–435. Retrieved from http//doi.org/10.1016/j.foodchem.2008.02.020

Hoashi-Erhardt, W., Moore, P., Collins, D., Bary, A. and Cogger, C. (2013). Evaluation of day-neutral cultivars for organic strawberry production in Washington. Acta Hortic. 1001, 167-174 DOI: 10.17660/ActaHortic.2013.1001.18

Hoashi-Erhardt, W. and Walters, T. (2014). Growing day-neutral strawberries in Western Washington. WSU Extension Retrieved from https://research.libraries.wsu.edu:8443/xmlui/bitstream/handle/2376/4912/FS132E.pdf?sequence=2&isAllowed=y

Hoover, E., Rosen, C., Luby, J. and Wold-Burkness, S. (2016). Day-neutral strawberry production in Minnesota. University of Minnesota, Minneapolis, MN. Retreived from http://fruit.cfans.umn.edu/strawberries/production/commercialproduction/

Hortyński, J. A., Żebrowska, J., Gawroński, J., & Hulewicz, T. (1991). Factors influencing fruit size in the strawberry (Fragaria ananassa Duch.).*Euphytica*, *56*(1), 67-74.

Hunt, A.R. (2007). Consumer interactions and influences on farmers' market vendors. Renewable Agriculture and Food Systems, (22) 54-66.

Hunter, B., Drost, D., Black, B. (2012). Improving growth and productivity of early-season high tunnel tomatoes with targeted temperature additions. HortScience **47**:733–740.

Ilbery, B. and Maye, D. (2005). Food supply chains and sustainability: evidence from specialist food producers in the Scottish/English borders. Land Use Policy, (22) 169-174

ISPR (2012). Kansas statistical abstract enhanced online. Section 2: Agriculture. Institute for policy and social research.

Jia, W., Wang, Y., Zhang, S., & Zhang, J. (2002). Salt-stress-induced ABA accumulation is more sensitively triggered in roots than in shoots. *Journal of Experimental Botany*, *53*(378), 2201-2206.

Jin, P., Wang, S. Y., Wang, C. Y., & Zheng, Y. (2011). Effect of cultural system and storage temperature on antioxidant capacity and phenolic compounds in strawberries. Food Chemistry, 124, 262–270.

Johnson, G. (2011). High temperatures can affect strawberry yields. Retrieved from https://agdev.anr.udel.edu/weeklycropupdate/?tag=abiotic-stress&paged=2

Joseph, J.A., Shukitt-Hale, B., Denisova, N.A., Bielinski, D., Martin, A., McEwen, J.J. and Bickford, P.C. (1999). Reversals of age-related declines in neuronal signal transduction, cognitive, and motor behavioral deficits with blueberry, spinach, or strawberry dietary supplementation. J. of Neurosci. 19(18):8114-8121.

Juaron, R. and Klein, W. (2011). Yard and garden: growing strawberries. Iowa State University Extension and Outreach, Ames, IA. Retrieved from http://www.extension.iastate.edu/article/yard-and-garden-growing-strawberries

Kader, A.A. (1988). Influence of pre-harvest and postharvest environment on nutritional composition of fruits and vegetables, In: B. Quebedeaux and F.A. Bliss (eds.). Horticulture and human health, conditions of fruits and vegetables. Prentice- Hall, Englewood Cliffs, NJ. p. 18-32.

Kader, A. A. (1991). Quality and its maintenance in relation to the postharvest physiology of strawberry. *The strawberry into the 21st century. Timber Press, Portland, OR*, 145-152.

Kader, A.A. (1992). Postharvest technology of Horticultural Crops. Second ed. Univ. Calif. Div. of Agr. And nat. Resources, Publ. 3311, pp. 296.

Kader, A.A. (1995). Maturity, ripening, and quality relationships of fruit-vegetables. ISHS Acta Hort., 434:249–256, Strategies for Market Oriented Greenhouse Production.

Kader, A.A. (1999). Fruit maturity, ripening, and quality relationships. Acta Hort., 485:203-208.

Kadir, S. & Carey, E. (2004). "Off-season Strawberry Production under High Tunnel Compared to Open Field in Kansas." *HortScience* 39(4): 770. Conference Issue, 101st Annual International Conference of the American Society for Horticultural Science, Austin, TX, July 2004.

Kadir, S., Carey, E., & Ennahli, S. (2006a). Influence of high tunnel and field conditions on strawberry growth and development. J. of HortScience, 41 (2): 329-335.

Kadir, S., Sidhu, G., & Al-Khatib, K. (2006b). Strawberry (Fragaria× ananassa Duch.) growth and productivity as affected by temperature. *HortScience,41*(6), 1423-1430.

Kalt, W., Forney, C. F., Martin, A., & Prior, R. L. (1999). Antioxidant capacity, vitamin C, phenolics, and anthocyanins after fresh storage of small fruits. *Journal of Agricultural and Food Chemistry*, *47*(11), 4638-4644.

KC Public Food Hub Feasibility Study (2015). Kansas City, Missouri: New Venture Advisors. Retrieved from file:///C:/Users/KOIC175Nusers/Downloads/Kansas%20City%20Food%20Hub%20Feasibility%20Study%20(2).pdf

Kays, S. J. (1999). Preharvest factors affecting appearance. *Postharvest Biology and Technology*, *15*(3), 233-247.

Kevers, C., Falkowski, M., Tabart, J., Defraigne, J-O., Dommes, J., and Pincemail, J. (2007). Evolution of antioxidant capacity during storage of selected fruits and vegetables. J. Agric. Food Chem., 55:8596-8603.

Knewtson, S. J., Carey, E. E., & Kirkham, M. B. (2010). Management practices of growers using high tunnels in the central great plains of the United States. *HortTechnology*, *20*(3), 639-645.

Koike, S.T., Zalom, F.G., Larson, K.D. (2009). Bronzing of Strawberry Fruit as affected by production practices, environmental factors, and thrips. HortScience 44:1588-1593.

Kosar, M., Kafkas, E., Paydas, S., & Baser, K. H. C. (2004). Phenolic composition of strawberry genotypes at different maturation stages. *Journal of Agricultural and Food Chemistry*, *52*(6), 1586-1589.

Kumakura, H.,and Shishido, Y. (1994). The effect of daytime, nighttime, and mean diurnal temperatures on the growth of Morioka-16 strawberry fruit and plants. Journal of the Japanese Society for Horticultural Science, 62: 827–832.

Lamont, W. J. (2009). Overview of the use of high tunnels worldwide. *HortTechnology*, *19*(1), 25-29.

Lantz, W., Demchak, K., & Swartz, H. (2010a). An Integrated Approach to developing a day neutral strawberry production industry. University of Maryland Extension. SARE LNE06-241

Lantz, W., Swartz, H., Demchak, K., & Frick, S. (2010b). Season-long Strawberry Production with everbearers. University of Maryland Extension. SARE LNE06-241

Lester, Gene E., Lewers, Kim S., Medina, Marjorie B., Saftner, Robert A. (2012). Comparative analysis of strawberry total phenolics via Fast Blue BB vs. Folin-Ciocalteau: Assay interference by ascorbic acid. J. Food Comp. and Analysis 27 (1):102-107. doi:10.1016/j.jfca.2012.05.003

Lopes da Silva, F., Escribano-Bailon, M. T., Alonso, J. J. P., Rivas-Gonzalo, J. C., & SantosBuelga, C. (2007). Anthocyanin pigments in strawberry. LWT, 40, 374–382.

Low, S. A., Adalja A., Beaulieu, E., Key, N., Martinez, S., Melton, A., Perez, A., Ralston, K., Stewart, H., Suttles, S., Vogel, S. and Jablonski, B.B.R. (2015). Trends in U.S. Local and Regional Food Systems, AP-068, U.S. Department of Agriculture, Economic Research Service.

Martinez, S., Hand, M., Da Pra, M., Pollack, S., Ralston, K., Travis, S., Vogel, S., Clark, S., Lohr, L., Low, S., Newman, C. (2010). Local Food Systems: Concepts, Impacts, and Issues. U.S. Department of Agriculture, Economic Research Service. Report 97.

Moore, J.N., G.R. Brown, and E.D. Brown. 1970. Comparison of factors influencing fruit size in large-fruited and small-fruited clones of strawberry. J. Amer. Soc. Hort. Sci. 95:827-831.

Moyer, R. A., Hummer, K. E., Finn, C. E., Frei, B., & Wrolstad, R. E. (2002). Anthocyanins, phenolics, and antioxidant capacity in diverse small fruits: Vaccinium, Rubus, and Ribes. Journal of Agriculture and Food Chemistry, 50, 519–525.

Olsson, M. E., Ekvall, J., Gustavsson, K. E., Nilsson, J., Pillai, D., Sjöholm, I., ... & Nyman, M. G. (2004). Antioxidants, low molecular weight carbohydrates, and total antioxidant capacity in strawberries (Fragaria× ananassa): effects of cultivar, ripening, and storage. *Journal of Agricultural and Food Chemistry*, *52*(9), 2490-2498.

Ordidge, M., García-Macías, P., Battey, N. H., Gordon, M. H., Hadley, P., John, P., et al. (2010). Phenolic contents of lettuce, strawberry, raspberry, and blueberry crops cultivated under plastic films varying in ultraviolet transparency. Food Chemistry, 119, 1224–1227.

Parchomchuk, P., & Meheriuk, M. (1996). Orchard Cooling with Pulsed Overtree Irrigation to Prevent Solar Injury and Improve Fruit Quality ofJonagold'Apples. *HortScience*, *31*(5), 802-804.

Perez, A. and Plattner, K. (2014). Fruit and tree nuts outlook. United States Department of Agriculture Economic Research Service, p. 23.

Petran, A., Hoover, E., Hayes, L. & Poppe, S. (2016). Yield and quality characteristics of day-neutral strawberry in the United States upper Midwest using organic practices. Biological Agriculture & Horticulture, 1-16. http://dx.doi.org/10.1080/01448765.2016.1188152

Phelps, D. (2014). Growing Under Cover: A Guide to Polytunnel Options for Kansas Growers, a Kansas Rural Center publication, Topeka, KS.

Piljac-Zegarac, J., Samec, D., Piljac, A., Mesic, A., & Tkalcec, Z. (2011). Antioxidant properties of extracts of wild medicinal mushroom species from Croatia. *International journal of medicinal mushrooms*, *13*(3).

Pirog, R. and McCann, N. (2009). Is local food more expensive? A consumer price perspective on local and non-local foods purchased in Iowa. Leopold Center for Sustainable Agriculture, Ames, IA.

Poling, B.E. 2012. Strawberry plant structure and growth habit. New York State Berry Growers Association, Berry EXPO, 2012, handout. Cornell Univ., Ithaca, NY.

Prior, R. L., Hoang, H. A., Gu, L., Wu, X., Bacchiocca, M., Howard, L., ... & Jacob, R. (2003). Assays for hydrophilic and lipophilic antioxidant capacity (oxygen radical absorbance capacity (ORACFL)) of plasma and other biological and food samples. *Journal of Agricultural and Food Chemistry*,*51*(11), 3273-3279.

Prior, R. L., Cao, G., Martin, A., Sofic, E., McEwen, J., O'Brien, C., ... & Mainland, C. M. (1998). Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of Vaccinium species.*Journal of Agricultural and Food Chemistry*, *46*(7), 2686-2693.

Pritts, M. & Dale, A. (1989). Dayneutral strawberry production guide. Cornell Cooperative Extension, Ithaca, NY. Retrieved from https://ecommons.cornell.edu/bitstream/handle/1813/3275/Dayneutral%20Strawberry%20Production%20Guide.pdf?sequence=2&isAllowed=y

Pollack, S., & Perez, A. (2008). Fruit and tree nuts situation and outlook yearbook 2008. *Washington, DC: US Department of Agriculture-Economic Research Service*.

Rekika, D., Khanizadeh, S., Deschênes, M., Levasseur, A., Charles, M. T., Tsao, R., & Yang, R. (2005). Antioxidant capacity and phenolic content of selected strawberry genotypes. *HortScience*, *40*(6), 1777-1781.

Rivard, C. (2014). Survey presented at the Great Plains Growers Conference, St. Joseph, KS. Unpublished data.

Rowley, D., Black, B.L., and Drost, D. (2011). Late-season strawberry production using day-neutral cultivars in high-elevation high tunnels. J. of HortScience, 46 (11), 1480-1485.

Roos, S. & Jones, D. (2012). Season extension: Introduction and basic principles. North Carolina State Extension. Retrieved from https://growingsmallfarms.ces.ncsu.edu/search-results/?q=season+extension

Ruan, J., Lee, Y. H., & Yeoung, Y. R. (2013a). Flowering and fruiting of day-neutral and ever-bearing strawberry cultivars in high-elevation for summer and autumn fruit production in Korea. *Horticulture, Environment, and Biotechnology*, *54*(2), 109-120.

Ruan, J., Lee, Y. H., Hong, S. J., & Yeoung, Y. R. (2013b). Sugar and organic acid contents of day-neutral and ever-bearing strawberry cultivars in high-elevation for summer and autumn fruit production in Korea. *Horticulture, Environment, and Biotechnology*, *54*(3), 214-222.

Sager, W. (2008). Definition of local food explored by small farm specialist. *Iowa State Daily*, p. 1-3. Retrieved from http://www.iowastatedaily.com/news/article_be363d01-262b-58f2-b1cd-4d95451e7b0f.html

Samec, D., Maretić, M., Lugarić, I., Mešić, A., Salopek-Sondi, B., & Duralija, B. (2016). Assessment of the differences in the physical, chemical and phytochemical properties of four strawberry cultivars using principal component analysis. *Food chemistry*, *194,* 828-834.

Santos, B.M., Salamé-Donoso, T.P., Chandler, C.K. and Sargent, S.A. (2010). Protected Culture for Vegetable and Small Fruit Crops: High Tunnels for Strawberry Production in Florida. UF/IFAS HS1162/HS407. Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu/hs407.

Scalzo, J., Politi, A., Pellegrini, N., Mezzetti, B., & Battino, M. (2005). Plant genotype affects total antioxidant capacity and phenolic contents in fruit.*Nutrition*, *21*(2), 207-213.

Schwieterman, M. L., Colquhoun, T. A., Jaworski, E. A., Bartoshuk, L. M., Gilbert, J. L., Tieman, D. M., ... & Sims, C. A. (2014). Strawberry flavor: diverse chemical compositions, a seasonal influence, and effects on sensory perception. *PLoS One*, *9*(2), e88446.

Singleton, V. L. and Rossi, J. L. (1965). Colorimetry of total phenolics with phosphomolybdic–phosphotungstic acid reagents. American Journal of Enology and Viticulture, 16, 144–158.

Shewfelt, R.L. (1990). Quality of fruits and vegetables. J. of Food Technology, 44, 99-106.

Shewfelt, R.L. and Prussia, S.E. (1993). Postharvest handling: A systems approach. Academic Press, San Diego, pp. 358.

Shewfelt, R.L. (1999). What is quality? Postharvest Biol. Technol., 15; 197-200.

Sistrunk, W. A., & Morris, J. R. (1985). Strawberry quality: influence of cultural and environmental factors. In *Evaluation of quality of fruits and vegetables* (pp. 217-256). Springer US.

Smith, R. (2009). Producers should help consumer out of 'Rut'. Feedstuffs.

Starr, A., et al. (2003). Sustaining local agriculture: barriers and opportunities to direct marketing between farms and restaurants in Colorado. Agriculture and Human Values, (20) 301-321.

Strik, B. C., Stonerod, P., Bell, N., & Cahn, H. (1996, April). Alternative production systems in perennial and annual culture of june-bearing strawberry. In *III International Strawberry Symposium 439* (pp. 433-438).

Symons, G. M., Chua, Y. J., Ross, J. J., Quittenden, L. J., Davies, N. W., & Reid, J. B. (2012). Hormonal changes during non-climacteric ripening in strawberry. *Journal of experimental botany, 63*(13), 4741-4750.

Szczesniak, A.S., & Smith, B.J. (1969). Observations on strawberry texture a three-pronged approach. *Journal of Texture Studies*, *1*(1), 65-89.

Takashima, M., Horie, M., Shichiri, M., Hagihara, Y., Yoshida, Y., & Niki, E. (2012). Assessment of antioxidant capacity for scavenging free radicals in vitro: A rational basis and practical application. *Free Radical Biology and Medicine, 52*(7), 1242-1252.

Thompson, J. F., Mitchell, F. G., & Kasmire, R. F. (2002). COOLING METHODS. *Postharvest technology of horticultural crops, 3311*, 97.

Timberlake, C. F. and Bridle, P. (1982). Distribution of anthocyanins in food plant. In Anthocyanins as Food Colors; Academic Press: New York, pp. 137.

Tulipani, S., Mezzetti, B., Capocaso, F., Bompadre, S., Beekwilder, J., de Vos, C. H., et al. (2008). Antioxidants, phenolic compounds, and nutritional quality of different strawberry genotypes. Journal of Agricultural and Food Chemistry, 56, 696–704

Tulipani, S., Marzban, G., Herndl, A., Laimer, M., Mezzetti, B., & Battino, M. (2011). Influence of environmental and genetic factors on health-related compounds in strawberry. *Food Chemistry*, *124*(3), 906-913.

U.S. Department of Agriculture National Agricultural Statistics Service (USDA-NASS) (2012). Census of Agriculture at:

http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

U.S. Department of Agriculture National Agriculture Statistics Service (USDA-NASS) (2007). Census of Agriculture at: http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

U.S. Department of Agriculture National Agricultural Statistics Service (USDA-NASS) (2009). Washington Field Office. Strawberry Historic Data at: http://www.nass.usda.gov/Statistics_by_State/Washington/Historic_Data/berries/strwbry.pdf

Van den Dool, K. (2006). Evaporative Cooling of apple and pear orchards. *University of Stellenbosch, Stellenbosch.*

Wang, H., Cao, G., & Prior, R. L. (1996). Total antioxidant capacity of fruits. *Journal of Agricultural and Food Chemistry*, *44*(3), 701-705.

Wang, S.Y., & Camp, M. J. (2000). Temperatures after bloom affect plant growth and fruit quality of strawberry. Scientia Horticulturae, 85, 183–189.

Wang, S.Y. and H. Lin. (2000). Antioxidant activity in fruits an leaves of blackberry, raspberry, and strawberry varies with cultivar and developmental stage. J. Agr. Food Chem. 48:140-146.

Wang, S. Y., Zheng, W. and Galletta, G. J. (2002). Cultural system affects quality and antioxidant capacity in strawberries. J. Agric. Food Chem. 50: 6534–6542.

Wells, O. S., & Loy, J. B. (1993). Rowcovers and high tunnels enhance crop production in the northeastern United States. *HortTechnology*, *3*(1), 92-95.

Wolf, K. L., Kang, X., He, X., Dong, M., Zhang, Q., and Liu, R. H. (2008). Cellular antioxidant activity of common fruits. J. Agric. Food Chem., 56:8418-8426.

Woods, M., Thornsbury, S. and Raper, K.C. (2012). Beyond Market Access: Values from food safety certification of fresh strawberries. Agribusiness: An International Journal, 28(4): 469-482.

Woodward, J. R. (1972). Physical and chemical changes in developing strawberry fruits. *Journal of the Science of Food and Agriculture*, *23*(4), 465-473.

Wu, X., Beecher, G. R., Holden J. M., Haytowitz, D. B., Gebhardt, S. E., and Prior, R. L. (2004). Lipophilic and hydrophilic antioxidant capacities of common foods in the United States. J. Agric. Food Chem., 52:4026-4037.

Yang, A. Li, H., Zhang, W.Y., Chung, Y.T., Liao, J., Yang, G.Y. (2011). Chemoprevention of Chronic Inflammatory Bowel Disease-Induced Carcinogenesis in Rodent Models by Berries. In *Berries and cancer prevention* Stoner, G. D. & In Seeram, N. P. (p. 228). New York: Springer.

Young, K. (2016, April 7th). *USDA launches first-ever local foods survey – study will provide new data on locally grown and sold foods* [News Release]. USDA Census of Agriculture.

Washington, DC. Retrieved from

https://www.agcensus.usda.gov/Newsroom/2016/04_07_2016.php