THE EVALUATION OF HIGH TUNNEL SYSTEMS FOR SPRING ORGANIC LETTUCE PRODUCTION IN GEORGIA

by

THEEKSHANA CHATHURANGA JAYALATH

(Under the Direction of Suzanne O'Connell)

ABSTRACT

High tunnels may help mitigate climate conditions and inclement weather threats to lettuce (*Lactuca sativa* L.) production yet there is a lack of information for the Southeast region. This study evaluated the effect of high tunnels, planting dates and cultivar selection on spring, organic lettuce. A greater marketable fresh weight for both butterhead and romaine lettuce was observed under high tunnels compared to the field in 2016 but not in 2015, indicating the advantage may depend on yearly weather conditions. Both years, the high tunnel lettuce was harvested 5 to 10 days earlier than the field. The greatest micro-environmental differences between the high tunnels and field included: air temperature on cold days, leaf wetness, and photosynthetically active radiation. Pests, diseases and physiological disorders were not different between the two systems. The butterhead cultivar "Sylvesta" and the romaine cultivar "Green Forest" consistently performed well in both systems.

INDEX WORDS: organic, high tunnel, hoop house, lettuce, farmers market, bolting, *Sclerotinia sclerotiorum*, photosynthetically active radiation

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DEDICATION

This thesis is dedicated to my loving family and friends who have supported me along the way to achieve this. Special thanks to my loving wife Samanthi for living with me and supporting and encourage me throughout the research period. Again, I would love to thank my daughter Nethuki for being with us and giving us an enjoyable and memorable two years. Finally, I would like to dedicate this accomplishment to all those who provided enormous support and encouragement to help me achieve this goal of mine, a Master's of Science Degree in Horticulture!

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CHAPTER 1

OVERVIEW OF RESEARCH TOPIC

Introduction

Lettuce Crop Characteristics:

Lettuce (*Lactuca sativa* L.) is a popular, cool-season vegetable that grows best with moderate daytime temperatures ~16-21^{o}C (~60-70^{o}F) and cool nights ~7^{o}C (~45^{o}F) (AgMRC, 2015). The major lettuce production areas are located in temperate and subtropical climates (Prohens-Tomás and Nuez, 2008). In 2009, the global lettuce production was estimated to be 24 million metric tons with China producing 54% and the U.S. producing 17% of the world's crop (Toland and Lucier, 2011b). In the United States (U.S.), California and Arizona dominate production with more than 98% of the nation's lettuce crop (Toland and Lucier, 2011b).

Production of lettuce has increased rapidly over the last two decades (Mousavi et al., 2012). The annual per capita consumption of lettuce in the U.S. was around 25 pounds in 2014 (ERS, 2014). Lettuce remains the second most popular fresh vegetable in the U.S. surpassed only by potatoes when considering both head and leaf lettuce together (PBH, 2015). Over the next five years, fresh vegetable consumption is expected to rise by 8% concurrent with a population growth of 4% (PBH, 2015) which suggests an increased demand for lettuce in the near future. The value of U.S. lettuce production in 2013 totaled nearly $1.5 billion, making lettuce the leading vegetable crop in terms of value (AgMRC, 2015).

Lettuce belongs to the Asteraceae plant family and is believed to be endemic to the eastern Mediterranean basin (Prohens-Tomás and Nuez, 2008). Evidence of crop domestication has been found in northwestern Europe and China dating back to between 600 and 900 A.D (Prohens-Tomás and Nuez, 2008). Domesticated lettuce has been classified into six main types based on leaf shape, size, head formation and stem type (AgMRC, 2015). The six types of lettuce are: 1) crisphead (*Lactuca sativa var capitata L.)*, 2) butterhead (*Lactuca sativa var capitata L.*), 3) romaine (*Lactuca sativa var longifolia Lam.)*, 4) leaf (*Lactuca sativa var crispa L.*), 5) stem (*Lactuca sativa var asparagina Bailey, syn. L.*), and 6) Latin (AgMRC, 2015; Tindall, 1983). There is a wide diversity of leaf shape, texture, color, gloss, size, etc. among different types of lettuce (Prohens-Tomás and Nuez, 2008).

In the beginning of the 20th century, butterhead lettuce was the most popular type in the U.S. However, in the 1940's iceberg lettuce became the preferred type because it could be grown at a larger scale using improved irrigation and shipping technologies for distribution to the rest of the country. In recent years, romaine lettuce has also become popular in the U.S. (Dufault et al., 2006). This may be due to its longer storage life and the rise in the consumption of Caesar salads (Mikel, 2007). While butterhead lettuce is grown on a more limited scale in the U.S. due to a more delicate head and shorter shelf life but is very popular in seasonal local farmers markets (Mikel, 2007).

Lettuce leaves are commonly used in salads and as a sandwich topping in the U.S., however in China and Egypt for example, stem lettuce is also very popular (Prohens-Tomás and Nuez, 2008). Some less common uses of lettuce around the world include: herbal cigarettes made with lettuce leaves, edible oil from lettuce seeds, and sedatives from lettuce stem latex sap (Prohens-Tomás and Nuez, 2008).

Lettuce is a self-pollinated annual plant which forms a taproot in addition to horizontal lateral roots near the soil surface. The above-ground portion of the plant usually consists of a spiral of leaves around a short middle stem forming a ‘head’ (Prohens-Tomás and Nuez, 2008). After reaching maturity, a single stem produces an inflorescence, containing many florets. When flowering starts before sufficient head or rosette growth it is referred to as ‘bolting’ (Simonne et al., 2002).

Stem internodes elongate during bolting can be accelerated by other than optimum air and root temperatures, photoperiod, excessive nitrogen fertilization, and/or gibberellins levels (Simonne et al., 2002; Waycott, 1995). Once a lettuce plant enters the reproductive growth stage or becomes stressed, a bitter taste develops in the plant tissues due to the development of lactones (Simonne et al., 2002). The primarily bitter sesquiterpene lactones (BSLs) in lettuce are lactucin, 8-deoxylactucin, and lactucopicrin (Seo et al., 2009). As a result, one of the major attributes in lettuce crop selection and breeding efforts is the development of cultivars with a slower tendency to bolt (Seo et al., 2009). Additional lettuce breeding efforts have targeted: size, shape, color, texture, taste, head formation, resistance to pests and diseases as well as adaptation to different climates (Guzman et al., 1992; Prohens-Tomás and Nuez, 2008).

U.S. Organic Market:

Organic agriculture is an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity while promoting a sustainable agroecosystem. Organic agriculture produces products using methods that protect the environment and primarily utilize naturally-derived materials (USDA, 2016). According to the USDA (2016) National Organic Standards Board, organic regulations prohibit the use of synthetic pesticides or herbicides, fertilizers, sewage-sludge, genetically modified organisms, antibiotics, artificial growth hormones, or irradiation. Organic farms must submit annual records and undergo annual inspections by a third-party, USDA approved certifying agency.

Soil organic matter levels in organic agricultural systems are generally higher than conventional systems which help to provide many benefits including conservation of soil, nutrient and water resources (Pimentel et al., 2005). Organic farming practices enhance soil fertility and biodiversity while depending less on external inputs (Maeder et al., 2002). Typical organic agricultural practices such as crop rotation and cover cropping help to reduce soil erosion and pesticide usage (Pimentel et al., 2005). In addition to the environmental benefits, higher prices may be obtained for organic products which may result in a greater net economic return per ha compared to conventionally produced crops (Pimentel et al., 2005).

The U.S. organic market currently represents about 5% of total food sales (OTA, 2016; USDA-NASS, 2016). Approximately, three out of four grocery stores as well as about 20,000 natural food stores offer organic products (OTA, 2016). Organic versions of more than 75% of supermarket products can be found (OTA, 2016). A continued rise in the consumer demand for organic products has made this sector the fastest growing sector of agriculture. U.S. organic exports increased by 58% between 2011-2014 (OTA, 2016). In 2009, this included approximately 320 million kilograms of lettuce which was worth of $430 million (Toland and Lucier, 2011a).

In an effort to supply the growing organic market, there has been a 300% increase in the number of USDA organic certified operations in the U.S. since 2002 (OTA, 2016). The number of certified organic businesses grew a record of 12% in 2015 to reach a total of nearly 22,000 operations, with a majority fruit and vegetable producers (ERS, 2016). According to the 2014 organic agriculture survey, there are about 1.5 million hectares (3.7 million) of organic agricultural land in the U.S. and more specifically, 3,636 hecatares (8,984 acres) in the state of Georgia (USDA-NASS, 2016).

According to the 2014 Organic Survey data, the organic products sold by U.S. farms were diverse from dairy and proteins (meat and eggs), to fruits, vegetables, and grains. In 2014, the top five organic commodities were milk, eggs, broiler chickens, lettuce, and apples in descending order (Young, 2015). The U.S. organic lettuce market is estimated to have a value of $264 million in 2014 (Young, 2015).

Georgia Climate:

Georgia’s humid sub-tropical climate is influenced by several factors including: ocean temperatures, land use, weather and climate events in the US and around the world (Knox, 2006). During the last several decade's, temperatures in the Southeast region, as well as the frequency of more extreme precipitation events and drought periods have steadily increased (Kunkel et al., 2013). According to Kunkel et al. (2013), several models have predicted that the number of extremely hot days in the Southeast will decrease or remain static while the number of warm nights will increase. Annual mean precipitation throughout the Southeast is predicted to increase as well as the number of wet days (Kunkel et al., 2013).

The state of Georgia’s climate varies considerably from the mountains in the north to the Lower Coastal Plain in the south. There are six major areas of differing soil types (Figure 1.1) (the Appalachian Plateau, the Valley and Ridge, the Blue Ridge, the Piedmont, the Upper Coastal Plain, and the Lower Coastal Plain) covering 153,909 km^2 (59,425 mi^2) of land (GDEcD, 2016; Usery, 2016). Air temperatures in the Coastal Plain can be at or above 32^oC (90^oF) for multiple consecutive months (Knox, 2006). Temperatures during the winter typically range from -6^{o}C (~20ºF) near the coast to -18^{o}C (< 0ºF) in the northeast mountains along with several snowfalls (GDEcD, 2016; Knox, 2006). The mean annual precipitation in Georgia during the last five years was approximately 1300 mm (51 inches), while the average monthly precipitation ranged from 86.5 mm (3.4 inches) in November and April to 135 mm (5.3 inches) in July (Knox, 2006; NOAA, 2016). Prevailing winds change across the state from season to season with an 8 to 15 km/h (5 to 9 mph) average monthly wind speed.

With the aforementioned climate conditions, Georgia farmers have a potential growing season that ranges from 180 to 270 days (Knox, 2006). Typical, fluctuating, and changing weather patterns can have negative effects on lettuce production in Georgia. Warm temperatures can lead to physiological disorders such as bolting and tipburn in lettuce heads while freezing temperatures can damage the leaves. In addition, strong winds can damage lettuce leaves while heavy rains and periods with high relative humidity may increase the incidence of fungal and/or soilborne diseases. Techniques that allow for better management of climate and weather conditions may help increase productivity and quality of lettuce production in Georgia.

High Tunnel Crop Production:

High tunnels (i.e., hoop houses) are unheated, passively ventilated greenhouse-like structures which can provide some protection to crops from adverse weather events (cold, freeze, hail, rain, wind, etc.), some insects or pests as well as offering season extension (Alves et al., 2014; Carey et al., 2009). Generally, high tunnels can be described as less complex and less expensive versions of a greenhouse. High tunnels utilize passive heating and cooling methods (i.e., by opening and closing side curtains and end walls, placing row covers to protect from frost damage, dragging shade cloths to protect from intensive sunlight, etc.) rather than active methods. High tunnels are relatively inexpensive in comparison to heated greenhouses (Alves et al., 2014). In the U.S., similar structures have been used in the nursery industry for decades (mostly for overwintering) but the application to vegetable production regained interest in the early 1990s (Wells and Loy, 1993).

High tunnels can be designed as temporary, movable, or semi-permanent structures with single-span or multi-span designs (Carey et al., 2009). These structures are usually covered with ultraviolet (UV) resistant 6-mil polyethylene greenhouse film (1 to 2 layers) and crops are grown in the soil in these tunnels (Carey et al., 2009). Sydorovych et al. (2013) found that 84% of the initial cost of a high tunnel construction is the material and the remainder delegated to labor. There is significant variability among cost estimates which is largely related to a grower's choices including: the size of the tunnel, the material choices, regional features, and availability. In general, construction of a high tunnel cost ranges from \$24.00 to \$54.00 per m^2 (10.8 ft^2) (Robbins and Gu, 2013). The material costs have been reported as approximately \$18.66 in Arkansas, \$37.32 in Michigan, and between \$26.12 - \$41.01 per m^2 in Minnesota (Conner et al., 2010; Foord, 2012; Robbins and Gu, 2013).

High tunnel bows which support the roof plastic are built with metal tubing or polyvinyl chloride (PVC). The amount and quality of the metal will add significantly to the overall cost and strength of the structure. Baseboards may consist of wood boards or metal pieces. Organic growers may be limited to either untreated wood that may need to be replaced every 4 to 5 years due to rotting, or metal framing especially at the soil interface. Most high tunnels have a manually operated curtain system to open and close the side walls. Automated side wall control systems can be integrated with an additional investment. There are many different designs for end walls.

It is estimated that the initial investment in a high tunnel can be recuperated within 2 to 5 years however, this will depend on the crop selection, the market, the environmental conditions and the grower's skill level (O'Connell, 2014). Growers with one high tunnel often add additional tunnels over time following the success of crop production in an initial high tunnel (Knewtson et al., 2010). The intensive labor requirement for high tunnel crop management is the main limitation, which may prevent expansion of this production system (Knewtson et al., 2010).

High tunnels can help farmers extend the season of crops which may result in premium prices, retention of markets and a more consistent income flow (Alves et al., 2014). Marketing locally grown produce may also provide additional value to their products. However, regional climates play a critical role in determining the yield and quality of high tunnel grown crops (Wallace et al., 2012).

Organic Production under High Tunnels:

Organic farmers that utilize high tunnels may be able to obtain a higher yield and/or quality product by controlling the micro-environment for optimum crop growth. A study conducted in Saskatchewan, Canada concluded that warm-season vegetables grown in high tunnels matured 1 to 2 weeks earlier and produced greater fruit yields (Waterer, 2003). Another study conducted in Goldsboro, NC concluded that with proper management, high tunnels can optimize yields, increase fruit quality, and provide season extension opportunities for high-value horticultural crops such as tomato (O'Connell et al., 2012). A study conducted in western Washington state showed significantly higher marketable yields from high tunnel grown lettuce and tomatoes compared to field grown (Galinato and Miles, 2013). Also, a muskmelon study conducted in Gainesville, FL indicates that, high tunnels can provide early and greater marketable yields, higher soluble solids concentration in fruits, and higher individual fruit weights (Waldo et al., 1998). Rogers and Wszelaki (2012) and Rogers et al. (2016) concluded that plant foliar diseases and insect population growth inside high tunnels are limited due to the modification of the internal micro-climate by the structure.

Results obtained from high tunnels, however, are often regionally-specific due to climate variations (Borrelli et al., 2013). Similar to field crop production, it is important to select the best planting date for high tunnel production systems. This can be specific to the type of crop as well as the climatic conditions of the region. Alves et al. (2014) indicated that planting of suitable cultivars and selecting the best planting date for the crop are essential to obtain the best yield using high tunnel systems. Several studies have found that planting date has a major role in determining the marketable yield and quality of high tunnel grown crops (Dufault et al., 2006; Rogers and Wszelaki, 2012). Therefore, determining the best planting date for high tunnel crop production will help maximize the benefits of these systems for lettuce production in Georgia.

Lettuce production in the Southeast has been limited due to the risk of early bolting, bitterness, tip burn, etc. Cultivar performance should be evaluated within high tunnel systems to identify differences in yield and quality parameters, as well as susceptiblity to regional pests and diseases (Simonne et al., 2002). Therefore conducting research to identify the most suitable high tunnel lettuce cultivars in the Southeast would be very beneficial.

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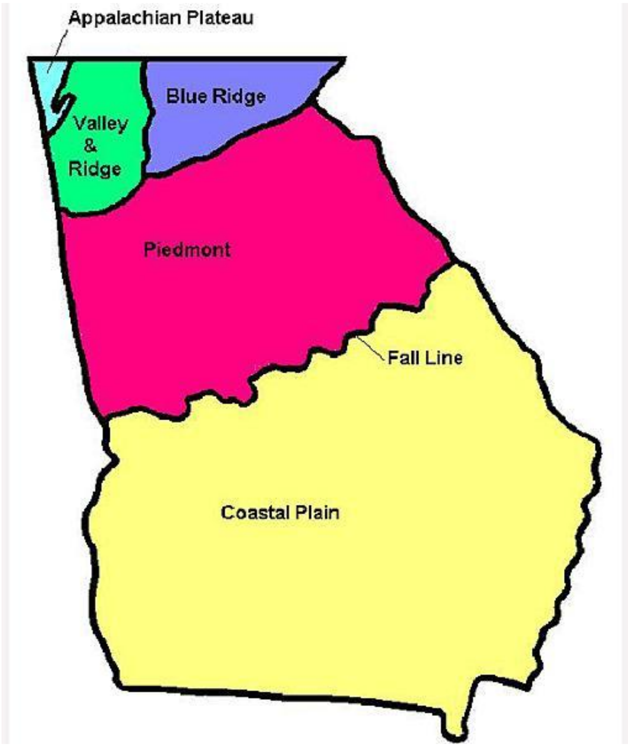

Figure: 1.1. Six Geographical Regions of Georgia (Usery, 2016).

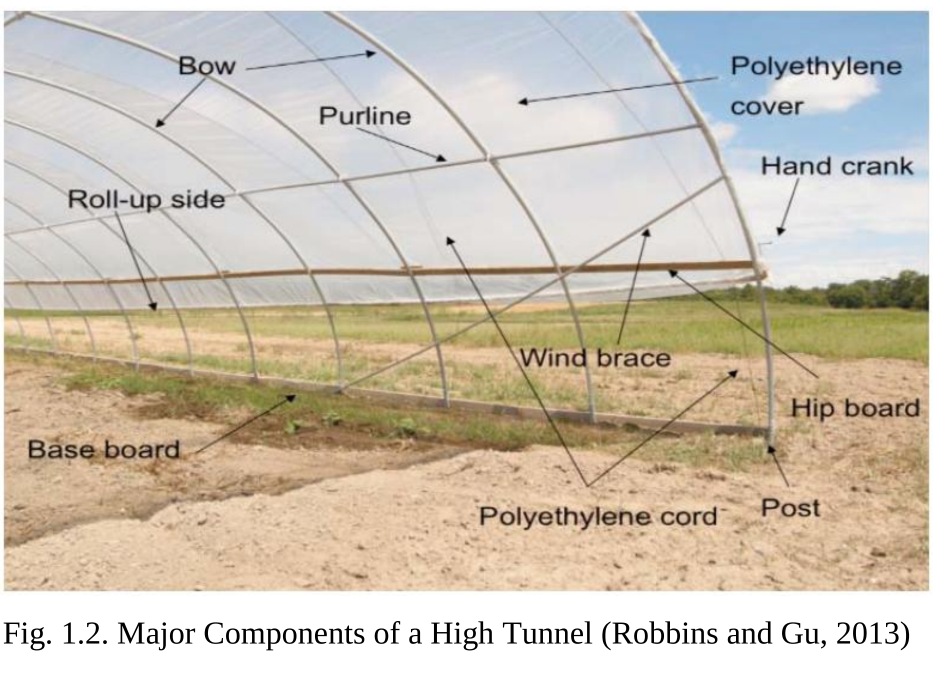

Fig. 1.2. Major Components of a High Tunnel (Robbins and Gu, 2013)

CHAPTER 2

THE EVALUATION OF HIGH TUNNEL SYSTEMS FOR SPRING ORGANIC LETTUCE PRODUCTION IN GEORGIA

Introduction

Lettuce (*Lactuca sativa* L.) is a very popular, cool-season vegetable. The majority of the crop is produced in California and Arizona (Toland and Lucier, 2011) however many other states such as Georgia have the ability to grow lettuce. Production techniques that help growers mitigate climate conditions and inclement weather would help increase lettuce production in the Southeast to meet the growing demand, especially for local and organic produce. From year 2005 to 2011 the amount of U.S. farm-land allocated to the organic lettuce production rapidly increased from 4% to 12% (ERS, 2013). This reflects a growing consumer demand for organic lettuce. In 2013, the average price for an organic lettuce head ($1.71) at the Atlanta, GA whole sale market was approximately 100% greater than the price of a conventionally grown lettuce head ($0.87) (ERS, 2014).

The annual mean temperature in Georgia ~12 to 20^{o}C (~54 to 68° F) (Knox, 2006) which matches the optimum lettuce crop temperature range ~16-21^{o}C/7°C (daytime/nighttime) (~60-70^{o}F/45^{o}F) for about nine months out of the year (AgMRC, 2015; Sanders, 2001). Also, there is plenty of light available in Georgia throughout the year (15 - 40 mol m^2 d^{-1}) for lettuce which requires a minimum of 15 mol m^2 d^{-1} (Waycott, 1995). Lettuce production during the summer months can be difficult due to average daily temperatures above the preferred range in combination with high relative humidity. These two factors may result in physiological disorders in lettuce such as bolting, bitterness and tipburn (Prohens-Tomás and Nuez, 2008).

In addition, the average daily temperature does not reflect the steady increase in extreme precipitation events and drought periods in the Southeast region over the last few decades (Kunkel et al., 2013). Precipitation events and related periods of high relative humidity may increase the incidence of fungal and/or soilborne diseases while strong winds can tear and abrade lettuce leaves. In addition, precipitation events before or during the crop season can delay preparation activities and limit worker access to field area. Management techniques that allow for increased crop protection and manipulation of the crop microenvironment have the potential to increase yield and quality of lettuce production in Georgia.

High tunnels (i.e., hoop houses) are unheated, passively ventilated greenhouse-like structures which can provide some protection to crops from adverse weather events (cold, snow, hail, rain, wind, etc.), some insects and pests, as well as extend the possibility for season extension (Alves et al., 2014; Borrelli et al., 2013; Carey et al., 2009). These structures can help extend the production season which may result in premium prices (Alves et al., 2014), retention of markets and a more consistent income flow. Furthermore, farmers that utilize high tunnels may be able to obtain a higher yield and/or quality product by controlling the micro-environment for optimum crop growth. Therefore, organic farmers in particular like high tunnels since consumers will always be more interested in expanding their purchases for great tasting higher quality products (Williams, 2012).

The initial investment to build a high tunnel structure ranges from \$24.00 to \$54.00 per m^2 (10.8 ft^2) which is lower than a greenhouse (Robbins and Gu, 2013). In addition, there are currently some competitive cost-share grant programs available to experienced farmers, administered by the USDA-NRCS, to construct high tunnels for crop production. Generally the payback period for the initial investment in high tunnels is estimated to range from two to five years (Sydorovych et al., 2013).

High tunnel benefits and management practices are often regionally-specific due to climate characteristics (Borrelli et al., 2013). Similar to the field production, it is important to select the best planting date and cultivars for high tunnel systems. These choices can be specific to the type of crop.

A romaine lettuce field study conducted in Charleston, S.C., to determine the best combination of planting dates and cultivars on yield and quality of romaine lettuce, has observed significant bolting occurred in the September, October, February and March planting dates, but negligible bolting in the November, December, and January planting dates (Dufault et al., 2006). According to Dufault et al. (2006), lettuce planted in September and April planting dates had shorter days to harvest (47 and 49 days respectively) compared to the lettuce planted in January, February, and March (98, 75, and 67 days respectively). This indicates physiological character (i.e. bolting, etc.) and yield parameters (i.e. days to harvest, etc.) varies on the planting date, but these results may change according to the regional climate conditions.

Other than that, Dufault et al. (2006) also indicate that, the cultivar “Green Forest” has performed better compared to other five romaine cultivars during the study. However, the best performing cultivar was not the same among all the planting dates. The best performing cultivars for September and February was “Green Forest” and “Ideal Cos’; October was “Tall Guzmaine”; November was “Apache” and December, January, March, and April was “Green Forest”.

Therefore, determining the planting date windows as well as the best-suited lettuce cultivar for regional unique growing conditions is important for high tunnel lettuce production in North East Georgia.

The goal of this study was to evaluate the effect of high tunnels on spring organic lettuce production in Georgia and investigate the effect of planting date and variety selection. The objectives included: 1) compare the lettuce yield (quantity and quality) in the high tunnel compared to the field system, 2) evaluate lettuce yield (quantity and quality) between three spring planting dates, 3) assess multiple butterhead and romaine lettuce cultivars and 4) collect micro-environmental data for both growing systems.

Materials and Methods

Site Characteristics and History:

A comparison of lettuce (*Lactuca sativa var capitata L. and Lactuca sativa var. logifolia Lam.*) production in high tunnel production compared to field production was conducted during the spring of 2015 and the spring of 2016 at the Durham Horticulture Farm located in Watkinsville, GA (lat 33°53'12.804" N, long. -083°25'9.876" W and elevation 236m). The plant hardiness zone for the site is 8a (USDA, 2012). The soil type at the site was a well-drained Cecil sandy clay loam subsoil (CYB2) that has been eroded overtime so that the plow layer now extends into the red sandy loam subsoil (USDA, 1968). Soil analysis indicated a pH of 6.6 and a composition of 67% sand, 15% silt and 18% clay just prior to the experiment (Agricultural & Environmental Services Laboratories, Athens, GA). The project site has been USDA certified organic since 2012 and all agricultural production methods were performed under these guidelines (7 U.S. C. § 6507).

High Tunnel Design:

Two commercial-size gothic-shaped high tunnels (Atlas Greenhouse Inc., Alapaha, GA) (29.26 m x 9.14 m (96 ft x 30 ft)) and an adjacent field area were used for the study (45.72 m x 9.14 m (150 ft x 30 ft)). High tunnels were constructed in an east-west orientation to be perpendicular to the prevailing winter winds at the site. Bows were spaced every 1.83 m (6 ft). The high tunnels had inflated double polythene film roofs comprised of 152.4 um (6 mil) plastic with 90% light transmission, 25% light diffusion, and blocking 95% of UV wavelengths <350 nm (SunView 4, POLY-AG. Corp, San Diego, CA). The end walls were comprised of 8 mm thick polycarbonate. Automated 1.83m (6 ft) tall z-lock drop-down side curtains constructed from 304.8 um (12 mil) weave fabric were utilized.

In both years, prior to our experiment the field area was planted with an oat cover crop (*Avena sativa)* at a rate of 112 kg ha^{-1} (100 lbs A^{-1}) (Welter Seed and Honey Co., Onslow, IA). An average dry weight of 1,111 kg ha^{-1} (992 lbs A^{-1}) of oat shoot biomass with a C:N ratio of 48:1 was tilled into the soil about four weeks before the first lettuce planting. The oat cover crop was predicted to release approximately 14 kg of available N ha^{-1} (30 lbs N A^{-1}) but we did not consider this credit for the subsequent lettuce crop. The high tunnel areas in contrast had been planted with a variety of Brassicaceae cash crops across the 2014-2016 fall/winter seasons prior to the lettuce crop.

Transplant Management:

Plants were grown in an organic greenhouse set to maintain air temperature between 12.8 and 21.1^{o}C (55-70^{o}F nighttime/daytime). Seeds were sown into 0.059 m (2.33 inch) deep 6-packs (#L-1206; Land Mark Plastics, Akon, OH) filled with potting soil (Sunshine Natural & Organic Professional Growing Mix #1; Sun Gro Horticulture, Agawam, MA). Mouse traps and yellow sticky cards were placed in several locations to protect seedlings. Overhead irrigation was administered by hand as needed. Two weeks after sowing, seedlings were thinned to limit growth to one plant per cell. A soluble fish and seaweed fertilizer [AgGrand Organic Series (4N-1.3P-2.5K); Amsoil, Inc., Superior, WI] was applied once per week at a rate of 7.82 ml L^{-1} of water (2 tablespoons per gallon) during the 3rd, 4th and 5th week after sowing. Approximately 13 to 14 L (3.5 gallons) of diluted fertilizer soultion was used for each application. Seedlings were acclimated to the outside environment approximately seven days before transplanting to either the high tunnel or field system.

When night temperatures during the acclimation period were predicted to be ≤ 4°C (≤ 40°F) transplants were covered with 18.6 g m^{-1}(0.6 oz yd^{-1}) weight row covers (Gro-Guard UV Row Cover # 20; Atmore Industries, Atmore, AZ) or if the temperature was predicted to be ≤ 0°C (≤ 32°F) transplants were brought back into the greenhouse to avoid cold damage prior to planting. In 2015, one night was predicted to be < -3.3°C (26°F), therefore seedlings were brought back into the heated greenhouse overnight and returned on the following day. In 2016, two evenings (03/19 and 04/09) were predicted to be < 4°C (36°F) and 0.5°C (33 °F); on those nights seedlings were covered with row covers.

Planting Date and Cultivar Selection:

Three planting dates (PD) (Table 2.2) were selected for the experiment by soliciting local farmer's ideas and by studying the last 20 years of weather data at the project site. Lettuce cultivars were selected after consulting with local organic farmers and several seed companies for recommendations for heat tolerant and/or top performing cultivars for the region. A few cultivars (Freckles and Red Rosie) were included for visual interest. The six butterhead cultivars included were: "Red Cross", "Sylvesta", "Adriana", "Skyphos" (Johnny's Selected Seeds,Winslow, ME), "Pirat", and "Mirlo" (High Mowing; Wolcott, VT). The six romaine cultivars included were: "Salvius", "Coastal Star", "Green Forest", "Red Rosie" (Johnny's Selected Seeds, Winslow, ME), "Super Jericho" (Harris Seed; Rochester, NY), and "Freckles" (High Mowing; Wolcott, VT). The butterhead cultivar "Skyphos" and the romaine cultivar "Freckles" were selected for their interesting color characteristics. In addition, farmer's advice for fertilizer regimes, crop management, high tunnel management, etc. were also used to inform our decisions and management practices.

Transplanting:

A total of eight raised beds were prepared in each high tunnel and field. Beds (71 cm wide x 20 cm tall (28 in x 8 in)) were 26.82 m (88 ft) long in the high tunnels and 45.72 m (150 ft) long in the field. Only six beds were used for the experiment. The two beds parallel to the side-walls in the high tunnel or the lateral edges of the field plots were designated as guard rows to minimize differential effects from environmental factors such as wind and light. Footpaths (46 cm wide (18 in)) were present between each experimental bed. As a result approximately 65% of the experimental area was planted with the lettuce crop.

Fertilizer applications were based on soil sample results taken one month before the lettuce crop was planted (Table 2.1). Fertilizers were applied one week before planting the lettuce crop. In both 2015 and 2016, fertilizers included: feather meal (13N-0P-0K) (Mason City By-products Inc., Mason City, IA), potash (0N-0P-41.5K-17S) (SQM North America, Atlanta, GA) and boron (10% B) (Sun Coast, Sodus, MI). In 2016, magnesium sulfate (Rite Aide, Camp Hill, PA) was also added to the high tunnel system and dolomitic lime (Imerys Carbonates., Roswell, GA) was added to the field system. Fertilizers were broadcasted over each planting bed by block and incorporated into the soil surface approximately 2.5 cm (1in) deep using rakes.

Beds were irrigated for several hours (1-3 hrs.) via drip tape prior to transplanting the seedlings. In 2016, Contans WG (Sipcam Agro USA, Inc., Durham, NC) a biological fungicide containing (*Coniothyrium minitans)* was also applied to the surface of raised beds, at a rate of 2.3 Kg Ha^{-1} (2lb A^{-1}) following the incorporation of the fertilizers and as a soil drench with a watering can at the time of lettuce transplanting. This product was utilized to reduce the lettuce drop (*Sclerotinia sclerotiorum)* disease pressure.

Experimental Design:

The experiment was split-split plot design. The whole plot factor consisted of the growing system type (i.e., high tunnel or field), the split-plot was one of three planting dates, and the split-split plot was cultivar type. The experimental unit was 10 plants per plot. Two of the six experimental beds were randomly assigned to planting date 1 (PD1), planting date 2 (PD2) or planting date 3 (PD3). Planting date treatments were three weeks apart from each other (Table 2.2). The anticipated first planting date was delayed by one week in 2015, followed by planting date two and three. The field bed preparation was delayed for planting date one due to multiple heavy rain events. It was a drier spring in 2016 and transplanting was carried out according to the original target planting dates. Lettuce seedlings were planted in two rows per bed and in a staggered arrangement with 30.48 cm (12 in) between-rows and 25.4 cm (10 in) within-row. One guard row per bed was planted at the PD1 date and the other at PD3 date in order to have the continuous crop growth throughout the research period.

Systems Management:

The majority of the season, irrigation was administered every other day but this depended on the current weather and soil moisture conditions. There was one drip tape (Toro Micro-irrigation., El Cajon, CA) per row (i.e, 2 drip tapes/ bed) with emitters every 20 cm (8 in) and a flow rate of 77 $L\ h^{-1}$ (0.34 gal min^{-1}) per 31 m (100 ft). In 2015, each irrigation cycle was run for 1½ to 2 hours depending on the plant growth stage. In 2016, the irrigation cycles were reduced to

1 hour to try and minimize the amount of time the soil surface was wet in order to try and reduce the incidence of lettuce drop disease.

Automatic drop-down side curtains were set to close at 10 ± 1°C (50 ± 2°F) and the end-walls were closed manually. Side curtains were closed when rain or winds (>15 mph) were predicted; however, to maintain the inside temperature end-walls were kept open. When the air temperature was predicted to be ≤0°C (32°F), intermediate weight row covers (18.6 g m^{-1} (0.6 oz yd^{-1})) were used for frost protection in both the high tunnel and field systems (Gro-Guard UV Row Cover # 20; Atmore Industries, Atmore, AZ). Row covers were draped over 9-gauge galvanized wire hoops spaced every 1.83 m (6 ft) and edges held in place with weighted sand bags. The hoops were approximately 0.5 m (1.7 ft) above the soil line at their apex. Weeding was done several times throughout the growing period with hand tools.

Environmental Monitoring:

Environmental monitoring stations were located in each high tunnel and field block (Em50 Digital/Analog Data Logger; Decagon Devices Inc: Pullman, WA). Each station included sensors to measure air temperature and relative humidity (VP-3), photosynthetic photon flux (PPF) (QSO-S PAR Photon Flux), soil temperature and soil moisture content (5TM), and leaf wetness (LWS). The air temperature probes were surrounded by plastic solar radiation shields, which were provided by the manufacturer. Average values for each parameter were recorded at hourly intervals. Using these hourly values, daily average, daily maximum, and daily minimum levels were calculated. A 24 hours day was considered as, from 7 am to 6 am of the following day. Soil moisture sensors were located between two emitters in the drip tape at a depth of 10-16 cm (4-6 in) from the soil surface. Photosynthetic active radiation (PAR) sensors, air temperature sensors, and leaf wetness sensors were placed 53, 46 and 31 cm (21, 18 and 12 inches) above the soil line, respectively. Leaf wetness sensors were mounted at a 45^{o} angle. The Photosynthetic Photon Flux (PPF) sensors and leaf wetness sensors were wiped with a clean, soft cloth at frequent intervals according to the manufacturer recommendations (Apogee Instruments, Logan, UT) to maintain the measurement accuracy throughout the growing season. Environmental monitoring stations were located within experimental beds and they were also covered with row covers on nights when temperatures were predicted to be < 0°C (≤ 32^{o}F).

Pest and Disease Management:

Integrated pest management (IPM) scouting was carried out, twice each week. In 2015, fire ants (*Solenopsis spp.*), aphids (*Aphidoidea spp.*), and armyworms (*Spodoptera exigua*) were the major pests along with the disease, lettuce drop (*Sclerotinia sclerotiorum*). Two spinosad-based products were used to manage fire ants including: “Entrust” naturalyte insect control (Dow Agro Sciences, Indianapolis, IN) and “Come and get it” fire ant killer bait (Ferti-lome, Bonham, TX). *Bacillus thuringiensis* (DiPel DF; Valent USA Cooperation, Walnut Creek, CA) was used once to manage armyworms at a rate of 1.12 kg ha^{-1} (1lb. A^{-1}). Plants infected with lettuce drop (*S. sclerotiorum)* were removed along with the surrounding surficial soil and visible sclerotia and disposed of in the trash. Dead or severely damaged plants, generally from fire ants or *S. sclerotiorum* infection, were recorded and replaced up to 2 weeks from their original transplanting date. After 2 weeks plants that died were not replaced and therefore resulted in fewer plants per plot.

Harvesting Protocols:

All plots were assessed two times per week. A plot was harvested when more than 75% of the plants were judged to have firm, mature, marketable size heads or when more than 25% of plants demonstrated signs of bolting, tip burn, or other defects. Judgments about marketable size were made from comparisons to lettuce for sale at local farmers markets and grocery stores. Lettuce heads were not washed prior to data collection.

The number and weight of marketable and non-marketable heads from each plot were recorded. The percent dry matter was calculated from two randomly selected marketable heads per plot which were subjected to 5 days in a forced-air oven at 60^{o}C (140°F). The percent dry matter from these sub-samples was used to estimate the dry weights of heads in each plot. Romaine head length, equatorial diameter, inner stem length and number of leaves (>10 cm (>4 inches)) were measured from two randomly selected heads from each plot. Butterhead length and equatorial diameter of two randomly selected butterheads from each plot were also measured. The number of bolted (pre-mature flowering) plants, plants with tip-burn, undersized heads/ no-closed head formation were also recorded as non-marketable.

Statistical Analysis:

Butterhead and romaine lettuce data were analyzed separately to allow for a comparison within lettuce type. In addition, each year was analyzed separately to identify effects of different weather conditions. For yield parameters, the statistical analysis was carried out using mixed effects ANOVA model with “PROC GLIMMIX” procedure with the SAS statistical software program (SAS Institute, Cary, NC). The Tukey’s mean separation method with 95% confidence level was used to determine the differences between production system type, planting dates, and cultivars. For the 2015 data, the mixed effects ANOVA model was not appropriate to analyze the marketable fresh weight of romaine lettuce due to the abnormalities in the residual distribution. Therefore, a generalized linear mixed effects model (i.e., binary logistic mixed effects model) was used to analyze the marketable fresh weight of 2015 romaine lettuce. The cultivar ‘Red Rosie’ which had low marketable heads was removed from the analysis in order to generate interaction effects between factors.

To calculate the differences of non-marketable categories (i.e. bolting, tip burn, and undersized heads) as well as the number of plants that died due to the lettuce drop disease, the same generalized linear mixed effects model was used. To determine the differences of micro-environmental parameters between two production systems and three planting dates the repeated measures ANOVA model was used.

Results

Micro-environmental Data:

High Tunnel vs. Field System Effects:

During the 2015 and 2016 growing seasons, the average daily air temperature was 0.7-0.8°C greater in the high tunnel compared to the field (P<0.0001) (Table 2.3 and 2.4). Also, the daily maximum and minimum temperatures were approximately 1°C greater in the high tunnel compared to the field (P<0.0001) (Table 2.3 and 2.4). On the coldest nights of the experiment season in 2015 and 2016 (3/28 and 3/21, respectively), the high tunnel system was approximately 4 and 3°C warmer than the field system (Fig. 2.1 and 2.2). And on the hottest days of the experiment in 2015 and 2016 (6/6 and 5/30, respectively), the high tunnel system was approximately 1.5 and 1.2°C warmer than the field system (Fig. 2.1 and 2.2). The overall range between minimum and maximum daily air temperatures was the same for the high tunnel and field systems, approximately 14°C in 2015 and 15°C in 2016.

The average daily soil temperature was greater in the high tunnel system (1.2-1.3°C) compared to the field (P<0.0030) in both years (Table 2.3 and 2.4). In 2015 and 2016, both daily maximum and daily minimum soil temperatures were approximately 2°C greater in the high tunnel compared to the field (P<0.0003) (Table 2.3 and 2.4). Unlike the air temperature range (14–15^{o}C), the overall range between minimum and maximum daily soil temperatures was lower in the high tunnel system (4.9°C) compared to the field system (6.6°C) (P<0.0156) (Table 2.3 and 2.4).

In 2015 and 2016, the average daily relative humidity was 1.6-1.8% lower in the high tunnels compared to the field (P<0.0036) (Table 2.3 and 2.4). However, the average daily relative humidity in 2015 for both production systems was in the mid-seventies while in 2016 it was in the high-sixties indicating that 2015 was a more humid season. In 2015, the average monthly relative humidity was 74% in March and 76% in April. In 2016, it was 70% in March and 66% in April (Table 2.3 and 2.4). The amount of rainfall received was greater in 2015 (328.2mm) compared to 2016 (169.4mm) (Fig. 2.3 and 2.4). As a result, the average amount of time with positive counts of leaf wetness (LWC) was greater in 2015 compared to 2016 (Fig.2.5 and 2.6). Furthermore, the average amount of time with positive counts of leaf wetness was lower in the high tunnel system compared to the field (P<0.0001) (Table 2.3 and 2.4).

In 2015 and 2016, the average daily *PAR* ranged from approximately 10 to 60 mol m^2 d^{-1}, increasing over the course of the growing season. The average daily *PAR* was 32-40% lower in the high tunnel system compared to the field (P<0.0001) (Table 2.3 and 2.4).

Planting Date Effects:

In 2015 and 2016, PD3 (21.8 and 21.5°C in 2015 and 2016, respectively) had a greater average daily air temperature than PD2 (20.0 and 18.5°C) which was greater than PD1 (18.1 and 17.0°C) (P<0.0001) (Table 2.5). Similarly, in both years, the average daily maximum and minimum air temperatures were greater for PD3 than PD2 which was greater than PD1 (P<0.0001) (Table 2.5). In 2015, the average difference between the daily maximum and minimum air temperatures ranged from 13.5 to 14.5°C across the planting dates. In 2016, the difference between the average daily maximum and minimum air temperatures ranged from 14.1 to 14.9°C.

In 2015 and 2016, the average daily soil temperature was lower for PD1 (19.7and 19.1°C in 2015 and 2016, respectively) and PD2 (21.8 and 20.8°C) compared to PD3 (24.4 and 23.7°C)

(P<0.0001) (Table 2.5). In 2015, the average daily maximum and minimum soil temperature differences were lower for PD1 (5.9°C) and PD2 (6.1°C) compared to PD3 (7°C) (P<0.0001). In 2016 the average daily maximum and minimum soil temperature differences were lower for PD1 (5.4°C) and PD2 (5.2°C) compared to PD3 (5.6C°) (P=0.0024) (Table 2.5). In 2015, no differences for soil moisture were observed among planting dates. In 2016, soil moisture was greater for PD1 (0.16 m^3/m^3 VWC) compared to PD3 (0.14 m^3/m^3 VWC) (P=0.0242) (data not shown).

In 2015, the average daily relative humidity was greater for PD1 (73.4%) compared to PD2 (72.8%) and PD3 (73%) (P<0.0001) (Table 2.5). In 2016, the average daily relative humidity was greatest for PD2 (68.7%) compared to both PD1 (68.0%) and PD3 (68.0%) (P<0.0001). The average relative humidity difference between high tunnel and the field system was approximately 1- 2% during the growing season (Table 2.5).

In 2015, no difference was observed among planting dates for the average number of minutes per day with wet leaf tissue (10-11 min. day^{-1}) (Table 2.5). However, in 2016, the average number of minutes per day with wet leaf tissue was greater for PD1 and PD2 (8-9 min. day^{-1}) compared to PD3 (6.5 min. day^{-1}) (P=0.0017) (Table 2.5). In 2015, during the months of March and April (where we observed significant lettuce drop incidence) more leaf wetness counts were observed compared to March and April in 2016 (Table 2.5 and 2.6).

In 2015, the average PAR level was lower for PD1 (31.6 mol m^2 day^{-1}) compared to PD2 (35.4 mol m^2 day^{-1}) compared to PD3 (39.9 mol m^2 day^{-1}) (P<0.0001) (Table 2.5). In 2016, the PAR level was also lower for PD1 (33.2 mol m^2 day^{-1}) and PD2 (34.3 mol m^2 day^{-1}) compared to PD3 (37.5 mol m^2 day^{-1}) (P<0.0001) (Table 2.5).

Yield Data:

High Tunnel vs. Field System Effects:

In 2015, the total marketable fresh weight of butterhead or romaine lettuce per plot was not significantly different among the high tunnel and field systems. However, in 2016 the total marketable fresh weight per plot for both butterhead and romaine lettuce were greater for the high tunnel compared to the field system (P=0.0392 and P=0.0138, respectively) (Table 2.6 and Table 2.7). The marketable fresh weight per plot for high tunnel butterheads was 768g greater than the field system in 2016. The marketable fresh weight per plot for high tunnel romaine lettuce was 1,233g greater that the field system in 2016.

In 2015, the individual fresh weight of butterhead and romaine lettuce (~292g and 432g) was similar among both the high tunnel and field systems. However, in 2016, the individual fresh weights for both butterhead and romaine lettuce were greater for the high tunnel system compared to the field system (P=0.0303 and P=0.0128, respectively) (Table 2.6 and 2.7). Across both years, the individual dry weight of butterhead and romaine lettuce was not significantly different among the high tunnel and field systems. In 2015, no difference was observed in the water content of butterhead and romaine lettuce tissues. However, in 2016, the water content of the butterhead and romaine lettuce tissue was 1- 3% greater for the high tunnel system compared to the field (P=0.0058 and P=0.0013) (Table 2.8 and Table 2.9).

In 2015, no difference was observed in the average length of either butterhead or romaine lettuce. However, in 2016, both butterhead and romaine lettuce had greater average lengths in the high tunnel compared to the field system (P=0.0003 and P=0.0005) (Table 2.8 and 2.9). In 2015, no difference was observed in diameters among butterhead or romaine lettuces. In 2016, the diameter of the butterhead and romaine lettuces was greater in the high tunnel compared to the field system (P=0.0134 and P=0.0219, respectively) (Table 2.8 and 2.9). In 2015 and 2016, the inner stem length and the average number of leaves per head of romaine lettuce were not different between the high tunnel and field systems (Table 2.9). The inner stem length and average number of leaves were not evaluated for the butterhead cultivars.

In 2015, the days to harvest was similar for butterhead and romaine lettuce between the high tunnel and field systems. However, in 2016, both lettuce types required fewer days to harvest in the high tunnel system compared to the field (P=0.0207 and P=0.0306) (Table 2.6 and Table 2.7). In 2016, butterhead and romaine lettuce were approximately seven days earlier in the high tunnels compared to field production.

In 2015 and 2016, both the high tunnel and field system had similar percentages of non-marketable butterhead and romaine lettuce heads attributed to: tip burn (3-6%), bolting (1-13%), and undersized heads (5-16%) (Table 2.6 and Table 2.7). In 2015, 3.5% of high tunnel butterhead lettuce and 0.7% of field butterhead lettuce were categorized as non-marketable due to bolting. In 2016, the percentage of bolting in the butterhead lettuce crop was approximately 1% in both growing systems. In 2015, 13-14% of romaine lettuce was categorized as non-marketable due to bolting in both growing systems. In 2016, the percentage of bolting for the romaine lettuce crop was approximately 5% in the high tunnels and 11% in the field system. In 2015, the percentage of tip burn of butterhead lettuce was approximately 6% in the high tunnels and <1% in the field. In 2016, the percentage of tip burn for butterhead was 5% in the tunnels while none was observed in the field. In both years, approximately 9-10% of the romaine plants were observed with tip burn in high tunnels and 2-3% in the field system (Table 2.6 and Table 2.7).

In 2015, approximately 6% of high tunnel butterhead crop and 11% of the field grown butterhead crop died due to *S. sclerotiorum* infection (Table 2.10). In the same year, approximately 9% of romaine lettuce plants died in each growing system due to the disease. In 2016, approximately 1% of butterhead lettuce plants died in each system due to the disease infection and approximately 4% of high tunnel romaine and 2% of field romaine died due to the *S. sclerotiorum* (Table 2.10).

Planting Date Effects:

In 2015, no difference was observed in marketable fresh weight of butterhead and romaine lettuce among planting dates. However, in 2016, both lettuce types had greater marketable fresh weights per plot for PD1 compared to PD2 and PD3 ($P=0.0001$ and $P<0.0001$) (Table 2.11). In 2015, the individual fresh weight of butterhead lettuce was greater for PD1 and PD2 compared to PD3 ($P=0.0038$) (Table 2.11). In 2016, the individual fresh weight of butterhead lettuce was greater for PD1 compared to both PD2 and PD3 ($P=0.0003$) (Table 2.11). In both 2015 and 2016, the average individual fresh weight of romaine lettuce was greater for PD1 compared to PD2 and PD3 ($P<0.0001$) (Table 2.11).

In 2015, the individual dry weight of butterhead lettuce was not different among planting dates. In 2016, the individual dry weight of butterhead lettuce was greater for PD1 compared to PD2 which was greater than PD3 ($P<0.0001$) (Table 2.11). In 2015, the individual dry weight of romaine lettuce was greater for PD1 and PD2 compared to PD3 ($P=0.0005$) (Table 2.11). In 2016, the individual dry weight of romaine lettuce was greater for PD1 compared to PD2 which was greater than PD3 ($P=0.0005$) (Table 2.11).

In 2015, the length of butterhead lettuce was greater for PD1 compared to PD3 (P=0.0097) (Table 2.8). In 2016, the length of butterhead lettuce was greater for PD1 compared to PD2 and PD3 (P= 0.0006) (Table 2.8). In 2015, the romaine lettuce length was not different among planting dates. However, in 2016, the length of romaine lettuce was greater for PD1 compared to PD2 which was greater than PD3 (P<0.0001) (Table 2.9).

In 2015, the diameter of butterhead lettuce was greater for PD1 compared to PD2 and PD3 (P=0.0136) (Table 2.8). In 2016, the diameter of butterhead lettuce was greater for PD1 compared to PD2 and PD3 (P<0.0001) (Table 2.8). In 2015, the average head diameter of romaine lettuce was not significant among planting dates. However, in 2016, the average head diameter of romaine lettuce was greater for PD1 compared to PD2 and PD3 (P<0.0001) (Table 2.9).

Across both years, the inner stem length of romaine lettuce was not significantly different among planting dates. In 2015, the average number of leaves for each romaine lettuce head was not different among planting dates. However, in 2016, the average number of leaves for each romaine lettuce head was greater for PD1 compared to PD and PD3 (P=0.0004) (Table 2.9).

In 2015, the percentage of water in the butterhead lettuce tissue was greater for PD1 and PD2 compared to PD3 (P=0.0204) (Table 2.8). In 2015, the percentage of water in the romaine lettuce tissue was greater for PD1 and PD3 compared to PD2 (P=0.0001) (Table 2.9). In 2016, the percentage of water in butterhead or romaine lettuce leaf tissue was not different among planting dates.

In 2015, the average number of days to harvest for the butterhead lettuce crop was greater for PD1 compared to PD2 which was greater than PD3 (P<0.0001) (Table 2.11). In 2016, the average number of days to harvest for the butterhead lettuce crop was greater for PD1 compared to PD3 (P=0.0105) (Table 2.11). In both 2015 and 2016, the average number of days to harvest for the romaine lettuce crop was greater for PD1 compared to PD2 which was greater than the PD3 (P<0.0001) (Table 2.11).

In 2015, the percentage of total non-marketable lettuce (i.e. the combination of bolting, tipburn and undersized heads together) per plot was not significantly different for either butterhead and romaine lettuce among planting dates. However, in 2016, the percentage of non-marketable for butterhead and romaine lettuce were greater for PD3 compared to PD1 and PD2 (P=0.0349 and P=0.0010) (Table 2.11). For 2016 romaine lettuce, the percentage of plants that bolted was greater for PD3 (17%) compared to PD1 (2%) and PD2 (6%) (P=0.0004) (Table 2.11).

In both years, there were no significance differences for the incidence of lettuce drop disease (*S. sclerotiorum*) for butterheads among planting dates (Table 2.10). In 2015, the percentage of lettuce drop disease incidence in romaine lettuce was greater for PD1 compared to PD3 (P=0.0455) (Table 2.10). In 2016, no differences were observed for the romaine crop.

In 2015, for both butterhead and romaine lettuce, no difference was observed for the marketable fresh weight per plot among planting dates for each system. However, in 2016 there was a significant interaction between growing system and planting date. The 2016 high tunnel lettuce had a greater marketable fresh weight per plot in PD1 compared to PD2 which was greater than PD3 (P=0.0121) (Table 2.12). The 2016 field butterhead lettuce had a greater marketable fresh weight per plot in PD1 compared to PD2 and PD3 (P=0.0241) (Table 2.12). In 2016, high tunnel romaine lettuce had a greater marketable fresh weight per plot in PD1 compared to PD2 which was greater than PD3 (P=0.0008) (Table 2.12). In the same year, the field romaine lettuce had a greater marketable fresh weight per plot in PD1 compared to PD2 and PD3 (P= 0.0046) (Table 2.12).

When comparing cultivar performance within each planting date between the two growing systems there was no difference observed in marketable fresh weight per plot for butterheads or romaine lettuce in 2015. However, in 2016 the butterhead lettuce had greater marketable fresh weight in the high tunnels compared to the field at PD1 and PD2 (P=0.0109 and P=0.0191) (Table 2.13). Similarly in 2016, the romaine lettuce had greater marketable fresh weight in the high tunnels compared to the field at PD1 and PD2 (P=0.0019 and P=0.0068) (Table 2.13). No differences were observed for 2016 butterhead or romaine PD3.

Cultivar Effects:

In 2015, the butterhead cultivars “Adriana” and “Sylvesta” had a greater marketable fresh weight compared to “Pirat” (P=0.0038) (Table 2.14). In 2016, the butterhead cultivar “Skyphos” had a greater marketable fresh weight compared to “Pirat” and “Red Cross” (P=0.0042) (Table 2.14). In 2015, the romaine cultivar “Green Forest” had a greater marketable fresh weight compared to “Freckles” and “Red Rosie” (P<.0001) (Table 2.15). In 2016, the cultivar “Green Forest” had a greater marketable fresh weight compared to “Freckles”, “Red Rosie”, “Coastal Star” and “Super Jericho” (P<0.0001) (Table 2.15).

Across both years, no difference was observed in fresh weight per head between butterhead cultivars. However, trends suggest that the butterhead cultivar “Adriana” had a slightly greater fresh weight in 2016. In 2015, the romaine cultivar Super Jericho had a greater fresh weight per head compared to all the other romaine cultivars (P<0.0001) (Table 2.15). In

2016, the romaine cultivar “Green Forest” had a greater fresh weight per head compared to “Red Rosie”, “Freckles”, “Coastal Star” and “Super Jericho” (P<0.0001) (Table 2.15).

In 2015, the butterhead cultivar “Adriana” had a greater dry weight per head compared to “Pirat” and “Skyphos” (P=0.0006) (Table 2.14). In 2016, the butterhead cultivar “Adriana” had a greater dry weight per head (16.5g) compared to all other cultivars evaluated (P<0.0001) (Table 2.14). In 2015, the romaine cultivars “Coastal Star”, “Green Forest”, and “Super Jericho” had greater dry weights per head compared to “Red Rosie” (P<0.0001) (Table 2.15). In 2016, “Red Rosie” and “Freckles” had lower dry weights per head compared to all the other romaine cultivars evaluated (P<0.0001) (Table 2.15).

In 2015, the butterhead cultivars “Adriana” and “Red Cross” had greater head length compared to “Mirlo” (P=0.0043) (Table 2.8). In 2016, the butterhead cultivars “Adriana”, “Red Cross”, “Skyphos”, and “Sylvesta” had greater head lengths compared to “Mirlo” (P<0.0001) (Table 2.8). In 2015, there was no difference observed in head length between romaine cultivars. However, in 2016, the romaine cultivar “Freckles” had the shortest head length compared to all other romaine cultivars (P<0.0001) (Table 2.9).

In 2015, neither butterhead nor romaine lettuce had differences in head diameters among cultivars. However, in 2016, the butterhead cultivar “Pirat” had the smallest head diameter compared to other cultivars (P=0.0007) (Table 2.8). In 2016, romaine cultivars “Freckles” and “Red Rosie” had the smallest average head diameters compared to all other cultivars (P<0.0001) (Table 2.9).

In 2015, butterhead cultivars “Pirat” and “Sylvesta” had a greater leaf tissue water content compared to “Red Cross” (P=0.0029) (Table 2.8). In 2016, the butterhead cultivars “Pirat” and “Skyphos” had a greater leaf tissue water content compared to “Adriana” (P=0.0026)

(Table 2.8). In 2015, the romaine cultivars "Green Forest" and "Salvius" had greater leaf tissue water content compared to "Red Rosie" (P=0.0118) (Table 2.9). In 2016, the romaine cultivars "Coastal Star" and "Super Jericho" had the lowest tissue water content compared to "Freckles", "GreenForest", "Red Rosie", and "Salvius" (P<0.0001) (Table 2.9).

Measures of inner stem length and number of leaves per head were performed only for romaine cultivars. In 2015, the inner stem length of romaine lettuce was not different among cultivars. However, in 2016, the romaine cultivar "Salvius" had longer inner stem length compared to "Freckles", "Red Rosie", and "Super Jericho" (P<0.0001) (Table 2.9). In 2015, the number of leaves per head of romaine lettuce was not different among cultivars. However, in 2016, the romaine cultivar "Super Jericho" had a greater number of leaves per head compared to "Coastal Star", "Green Forest", "Red Rosie", and "Salvius" (P<0.0001) (Table 2.9)

In 2015, the butterhead cultivars "Pirat" and "Sylvesta" had fewer days to harvest compared to "Red Cross" (P=0.0004) (Table 2.14). In 2016, the butterhead cultivars "Pirat" and "Sylvesta" had fewer days to harvest compared to "Mirlo", "Red Cross", and "Skyphos" (P<0.0001) (Table 2.14). In 2015, the romaine cultivar "Freckles" had the fewest number of days to harvest compare to all other romaine cultivars (P<0.0001) (Table 2.15). In 2016, the romaine cultivar "Freckles" had the fewest number of days to harvest compare to "Green Forest" and "Super Jericho" (P<0.0046) (Table 2.15).

In both 2015 and 2016, the butterhead cultivar "Pirat" had a greater percentage of non-marketable heads compared to "Skyphos", mainly because of the tip burn issues (P=0.0344 and P=0.0392, respectively) (Table 2.14). In 2015 and 2016, the percentage of either butterhead or romaine lettuce plants with undersized heads, or the incidences of lettuce drop were not different among cultivars. In both 2015 and 2016, the romaine cultivar "Freckles" had a greater percentage of non-marketable heads compared to the other romaine cultivars primarily due to bolting (P<0.0001) (Fig. 2.9 and Table 2.15).

Evaluation of cultivar performance within a growing system was as follows. In 2015, the butterhead lettuce cultivar “Adriana” had a greater marketable fresh weight per plot compared to “Pirat” in the high tunnel system (P<0.0001) (Fig. 2.11). In 2016, the butterhead cultivars “Adriana”, “Mirlo”, “Skyphos” had greater marketable fresh weights compared to cultivars “Pirat” and “Red Cross” in the high tunnel system (P<0.0001) (Fig. 2.11). In 2015 and 2016, no difference was observed for marketable fresh weight of butterhead lettuce within the field system.

In 2015, the romaine lettuce cultivar “Green Forest” had a greater marketable fresh weight per plot compared to cultivars “Coastal Star”, “Freckles”' and “Super Jericho” within the high tunnel system (P<0.0001) (Fig. 2.12). In 2015, the romaine cultivars “Green Forest” and Super Jericho” had greater marketable fresh weights compared to “Freckles” and “Red Rosie” within the field system (P<0.0001) (Fig. 2.12). In 2016, the romaine cultivars “Green Forest”, “Salvius”, and “Super Jericho” had greater marketable fresh weights compared to “Freckles” and “Red Rosie” within the high tunnel system (P<0.0001) (Fig. 2.12). In 2016, the romaine cultivar “Green Forest” had a greater marketable fresh weight per plot compared to cultivars “Freckles”, “Red Rosie”, and “Super Jericho” within the field system (P<0.0001) (Fig 2.12).

The growing system by cultivar interactions were as follows. In 2015, the marketable fresh weight per plot among butterhead cultivars was not different between the two growing systems and only one romaine cultivar displayed a significant growing system and cultivar interaction. In 2015, the romaine cultivar “Super Jericho” had a greater marketable fresh weight per plot in high tunnels compared to the field (P=0.0482) (Table 2.17). In 2016, the butterhead cultivars “Adriana”, “Mirlo”, “Skyphos”’ and “Sylvesta” had greater marketable fresh weight per plot in high tunnel compared to the field system (P<0.0001) (Table 2.16). Also, in 2016, the romaine cultivars “Coastal Star”, “Green Forest”, “Red Rosie”, “Salvius” and “Super Jericho” had greater marketable fresh weight per plot in the high tunnel compared to the field system (P<0.0001) (Table 2.16).

Discussion and Conclusions

A greater marketable fresh weight for both butterhead and romaine lettuce was observed in the high tunnel system compared to the field in 2016 but not in 2015. These results suggest that high tunnel systems can help increase the production potential of spring organic lettuce yield in Georgia but also indicates this advantage may depend on yearly weather conditions. Other high tunnel studies have also found similar results for high tunnel tomatoes in eastern North Carolina (O'Connell et al., 2012) and lettuce in Tennessee and Texas (Wallace et al., 2012). In addition, high tunnel lettuce was seven days quicker to harvest compared to the field system when planted on the same date in 2016 but not in 2015. This results are in agreement with a similar lettuce study also which obtained an earlier harvest in high tunnel compared to a field system (Wallace et al., 2012).

Overall, the air temperature of the high tunnel system was an average of 1°C warmer than the field across both years. On the coldest evenings during the experiment (March-June) the high tunnels were 3-5°C warmer than the field system. The added protection from the high tunnel system prevented the air temperature from dropping below 0°C. Yet when utilizing intermediate weight row covers over the lettuce plants in both the high tunnel and field systems on nights predicted to be less than <0° no frost damage occurred on any lettuce plants. This indicates that row covers may be sufficient protection for cold-acclimated spring lettuce exposed to temperatures around -3°C. Wells and Loy (1985) also found the similar result when reviewing the use of row covers for frost protection.

On the warmest afternoons during the experiment the high tunnels were approximately 0.5-1°C warmer than the field system. These results challenge the assertion that high tunnel systems are much hotter than the field on a warm, sunny day. The similarities between our high tunnel and field systems may be due to the fact that we placed the air temperature sensors at the height of the lettuce crop canopy which may be cooler than higher points in the high tunnel environment. Also our high tunnels included 1.83m tall side walls and a 4.9m wide end wall opening in order to maximize the ventilation capacity. Our protocols emphasized opening both side walls and end walls on warm, sunny days to maximize the cross-flow of air. Attention to high tunnel design and in particular ventilation capacity may be a key factor for regions that are subject to many warm, sunny days. Regardless, the average daily temperatures in both the high tunnels and field regularly exceeded optimum lettuce growing temperatures (~21-24°C) during mid- to late May across both years. This indicates that finishing a lettuce crop by early May in our region would be recommended if additional measures were not taken to cool the microenvironment (e.g., shade cloth).

The average daily soil temperature was also greater in the high tunnel system compared to the field but it rarely exceeded 24°C (the upper range of preferred daytime temperatures for lettuce). Trends on the coldest nights indicated that the high tunnel system soil temperature was approximately 2°C warmer than the field system across both years. The elevated high tunnel soil temperatures were reflected in greater daily minimum and mean temperatures but the maximum soil temperature was similar (~24.1-24.6°C) among the high tunnel and field system.

In our study both 2015 and 2016, the relative humidity levels ranged from 65-85% across the spring season with the highest values in June. However, the average relative humidity levels were greater in 2015 (~71-85%) compared to 2016 (~65-72%) because of the greater rainfall received in 2015. Overall, the relative humidity of the high tunnel system was approximately 2% lower than the field. This may be due to the fact that the slightly warmer high tunnel air was able to hold more moisture compared to the field. This result is slightly different than a study conducted in midwestern U.S. that indicated high tunnels did not cause a marked change in relative humidity compared with the open field (Zhao and Carey, 2009). In our study, although the relative humidity was slightly lower in the high tunnel system across the seasons, both environments had favorable conditions for fungal disease development.

Greater relative humidity and rainfall events during the study increased the leaf wetness duration and the potential of getting fungal infections. Both relative humidity and leaf wetness can influence the fungi during production and transport of inoculums (Huber and Gillespie, 1992). Greater relative humidity and rainfall events may be the reason that we observed greater plant loss from lettuce drop in 2015 (~9%) compared to 2016 (~3%).

During the growing season, the average daily PAR level in the field (30 - 50 mol m^2 d^{-1}) was within the mean range of last 30 years values for the region (Korczynski et al., 2002). However, the average daily PAR was reduced approximately 32% and 40% in the high tunnel system compared to the field in 2015 and 2016, respectively. Our double-layered, polyethylene roof was 2 to 3 years old during the experimental period. The reduction from year 2015 to 2016 may have due to plastic degradation due to physical damage, UV damage, dust, etc. however, the amount of PAR entering the high tunnel system was consistently above the recommended minimum light levels for lettuce (15 mol m^2 d^{-1}) (Runkle, 2011). A similar research study which evaluated leafy green production under high tunnels found a 27-36% reduction in PAR with a single layer of 0.15 mm ultraviolet-treated greenhouse plastic roof compared to the open field (Borrelli et al., 2013).

Differences were not discernible among non-marketable lettuce due to bolting or tip burn among the high tunnel and field system. This is in contrast to another study that found greater levels of bolting in high tunnels compared to field in Tennessee and Texas (Wallace et al., 2012). The lack of notable differences in maximum air and soil temperatures between the two growing systems in our study may be the reason we did not observe significant differences of bolting of tip-burn in 2015. However, when comparing 3 planting dates, in 2016, the last planting date (PD3) did have a greater incidence of bolting compared to PD1 in both growing systems. This is likely attributable to the greater air and soil temperatures and/or longer photoperiod associated with the later planting date (i.e. early vs. late spring). Although not conclusive, our measures of romaine inner stem length did not appear to be correlated with tendency to bolt. A South Carolina lettuce study also reported that planting romaine lettuce in warmer months of spring increased the percentage of lettuce with defects; they observed increased bolting in later spring planting dates as a result of increasing day length and temperatures (Dufault et al., 2006). However, faster heat unit accumulation in warmer months also accelerated the development and maturity of lettuce resulting in fewer days to harvest (Dufault et al., 2006).

For both butterhead and romaine lettuce the percentage of plants that died due to the lettuce drop (*S. sclerotiorum*) was not statistically different between two growing systems. However, in both years, PD1 tended to have a greater number of plant loss due to lettuce drop compared to PD3. According to Clarkson et al. (2014) the incidence of lettuce drop infections increases rapidly between 16–27^{o}C degrees and 70-100% relative humidity (RH) (Fig. 2.7 and Fig. 2.8). In 2015, conditions during the growing season were within these optimal ranges; the high tunnel system was an average of 20^{o}C and 72% RH and the field system average was 19^{o}C and 74% RH. However, the number of minutes leaf tissues were wet in high tunnels were significantly lower than the field. The incidence of lettuce drop infection did not appear to have a positive or predictive relationship with leaf tissue wetness counts as it may with other diseases.

Our results indicate that alternative measures of environmental moisture such as relative humidity, soil surface moisture, and/or or moisture at the lettuce crown should be further explored in lettuce drop field studies.

In 2016, the percentage of lettuce plants infected by lettuce drop (~2%) were lower than 2015 (~9%). This may be due to several differences among the two growing seasons. First, the amount of precipitation received in April, 2016 (62.5 mm) was lower than April, 2015 (188.2mm). This was also reflected in lower RH levels in April, 2016 (~66%) compared to April, 2015 (~76%). Also, we reduced the amount of time each irrigation cycle ran especially early in the season in 2016 to try and maintain a drier soil surface near the lettuce plants. Finally, we applied a parasitic fungus (*Coniothyrium minitans*) that is suppose to attack *S. Sclerotiorum* over time. This was only applied in 2016 and may have reduced the disease pressure the second year of the study. A lettuce study conducted to evaluate the efficacy of *Coniothyrium minitans* also states that a single application of "Contans" at planting significantly reduce the incidence of lettuce drop in all lettuce types even under high disease pressure (Chitrampalam et al., 2010).

Many high tunnel growers in this area, plant spring lettuce a few weeks earlier (~February) than our first planting date. Earlier planting dates would reap the benefit from cold protection and be harvested before the optimal average daily temperatures are surpassed in mid- to late May. It should be noted that in 2015, our first planting date in the field and subsequently the high tunnel was delayed due to saturated field conditions. This situation is a fairly common occurrence in our region in the early spring season. It is another reason in addition to yield effects that growers are interested in high tunnel systems as they provide reduced adverse environmental risks of preparation, planting and management activities in high tunnel systems.

In 2015 and 2016, the average number of days to harvest was (~5- 10 days) longer for PD1 compared to PD3. This is likely related to the increased temperature, day-length and/or light intensity over the course of the spring which resulted in quicker plant growth at the later planting dates. These results may help regional growers schedule their crop planning. A romaine lettuce study that compared multiple planting dates also indicated that the warmer planting dates needed fewer days to reach maturity compared to older planting days due to a greater accumulation of heat units and accelerated growth, development, and maturity (Dufault et al., 2006).

When comparing cultivar performance, the butterhead “Sylvesta” and the romaine “Green Forest” performed the best in both our high tunnel and field systems. Butterhead cultivars, “Adriana”, “Mirlo”, “Skyphos”, and “Sylvesta” had competitive yields, but “Sylvesta” had slightly shorter days to harvest than the other cultivars. The romaine cultivar “Green Forest” and “Salvius” had the greatest marketable yields in both years, but “Green Forest” appeared more tolerant to bolting. Conversely, the butterhead “Pirat” appeared to be more susceptible to tip burn and the romaine ‘Freckles’ was subject to a high level of bolting.

Overall, these results suggest that high tunnel systems can help increase the production potential of spring organic lettuce yield and will not exacerbate levels of bolting, tip burn or lettuce drop in Georgia. Although we did not test different high tunnel structures, it appears that the ability of out structures to ventilate well was keep to managing air temperatures on sunny and/or warm days. These results also point out that disease pressure and disorders related to heat may vary depending on yearly weather conditions. The greater air and soil temperatures and longer photoperiod associated with later spring planting dates may not be suitable for either high tunnel or field lettuce production in the region without additional measures taken to decrease heat and light. So, finishing a lettuce crop by mid-May in our region would be recommended if additional measures were not taken to cool the crop microenvironment.

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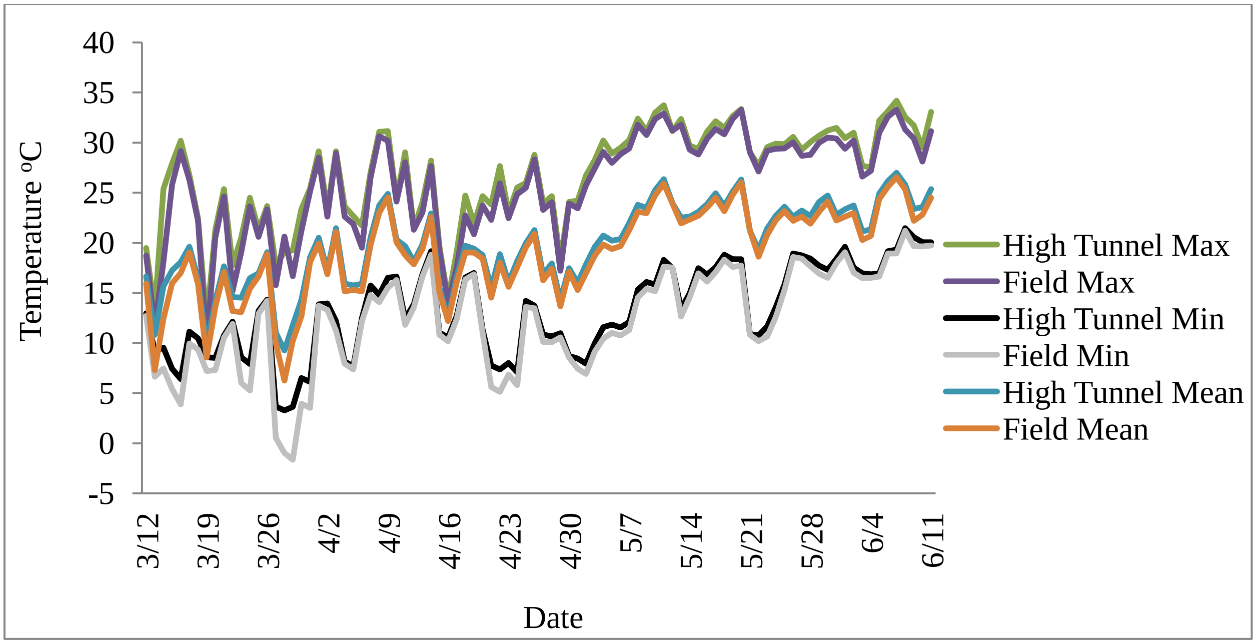

Fig. 2.1. 2015 Daily Maximum and Minimum Air Temperature by Growing System.

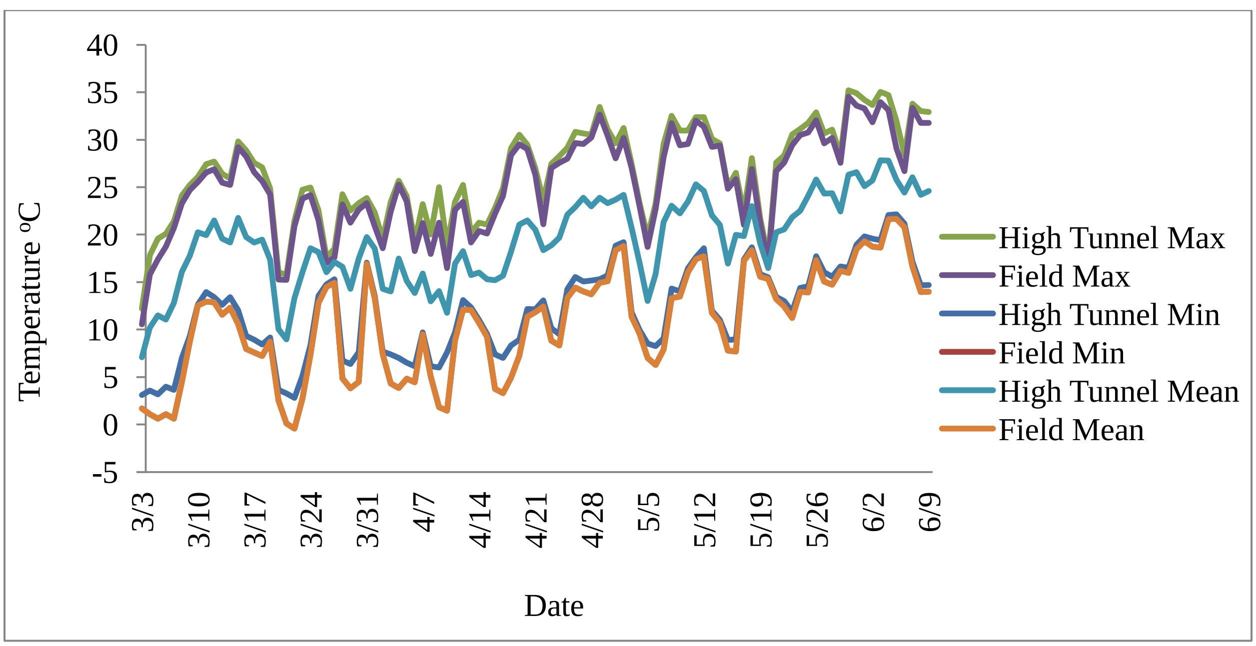

Fig. 2.2. 2016 Daily Maximum and Minimum Air Temperature by Growing System.

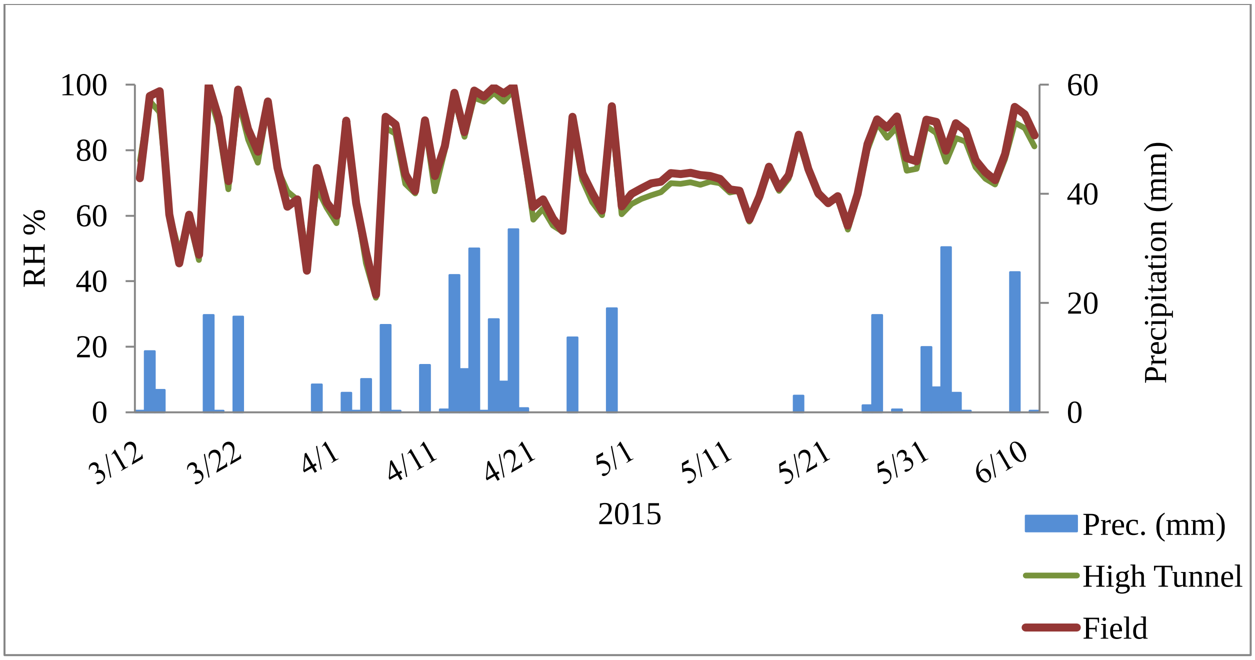

Fig. 2.3. 2015 Precipitation and Relative Humidity by Growing System.

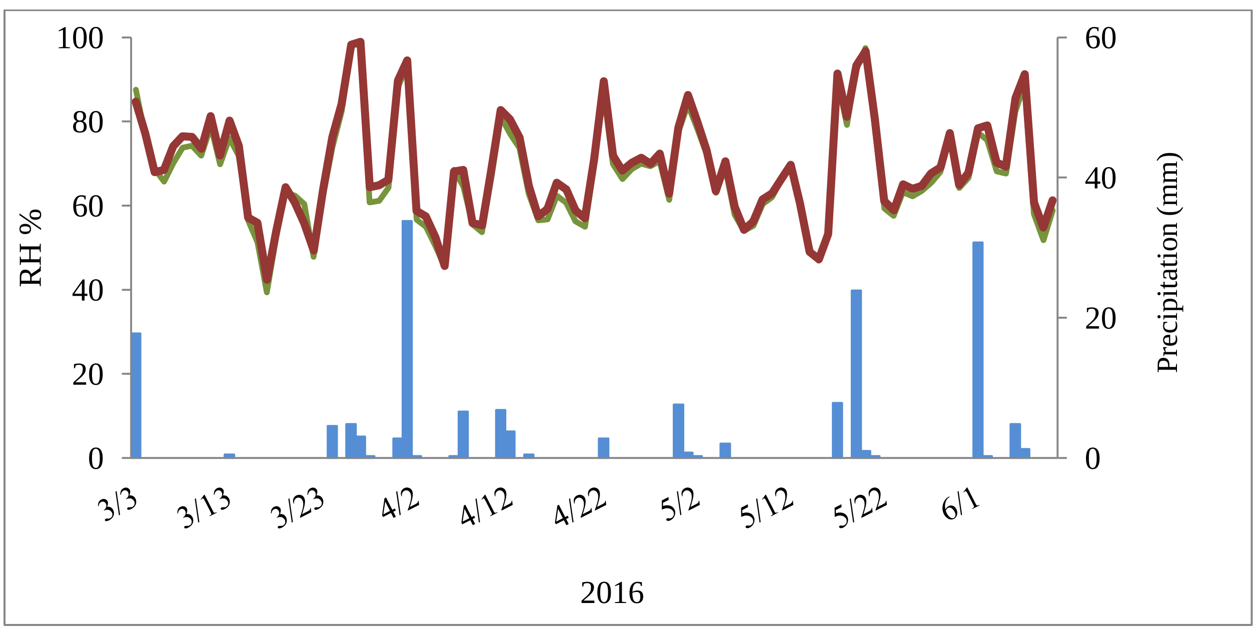

Fig. 2.4. 2016 Precipitation and Relative Humidity by Growing System.

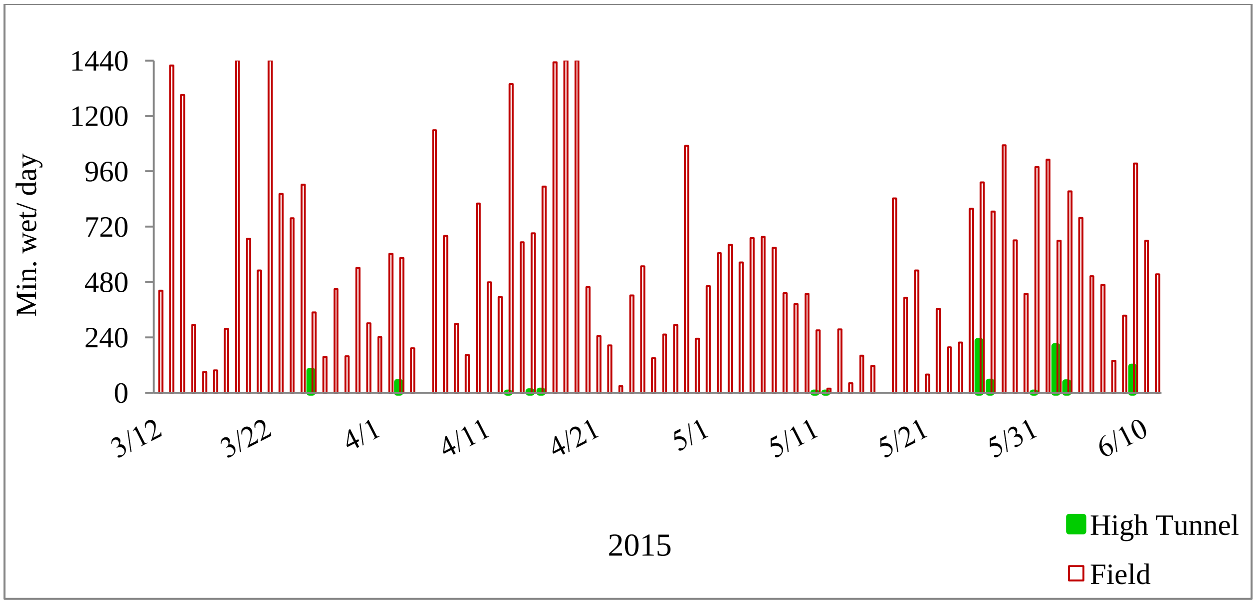

Fig. 2.5. 2015 Daily Leaf Wetness Counts by Growing System.

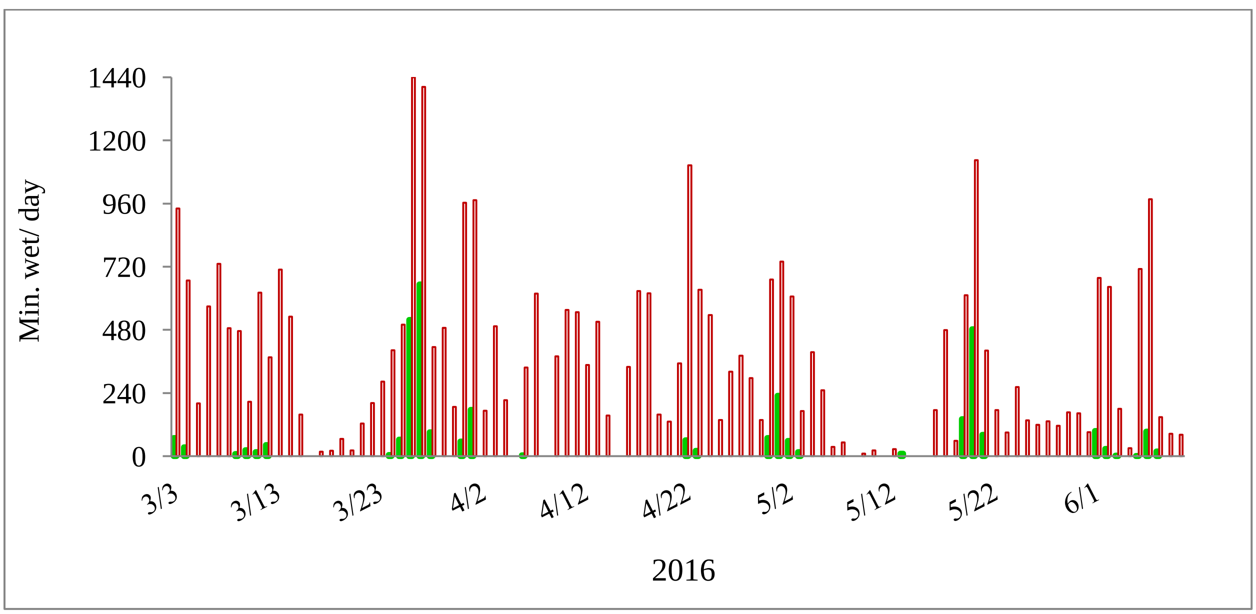

Fig. 2.6. 2016 Daily Leaf Wetness Counts by Growing System.

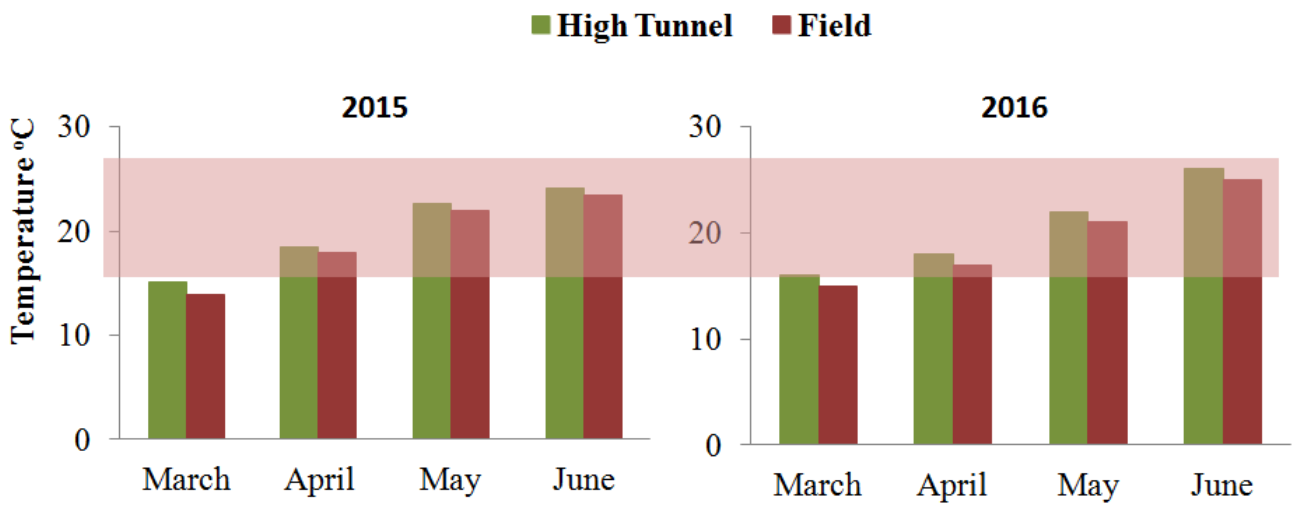

Fig. 2.7. Optimum Temperatures for Lettuce Drop (*S. sclerotiorum*) Disease.

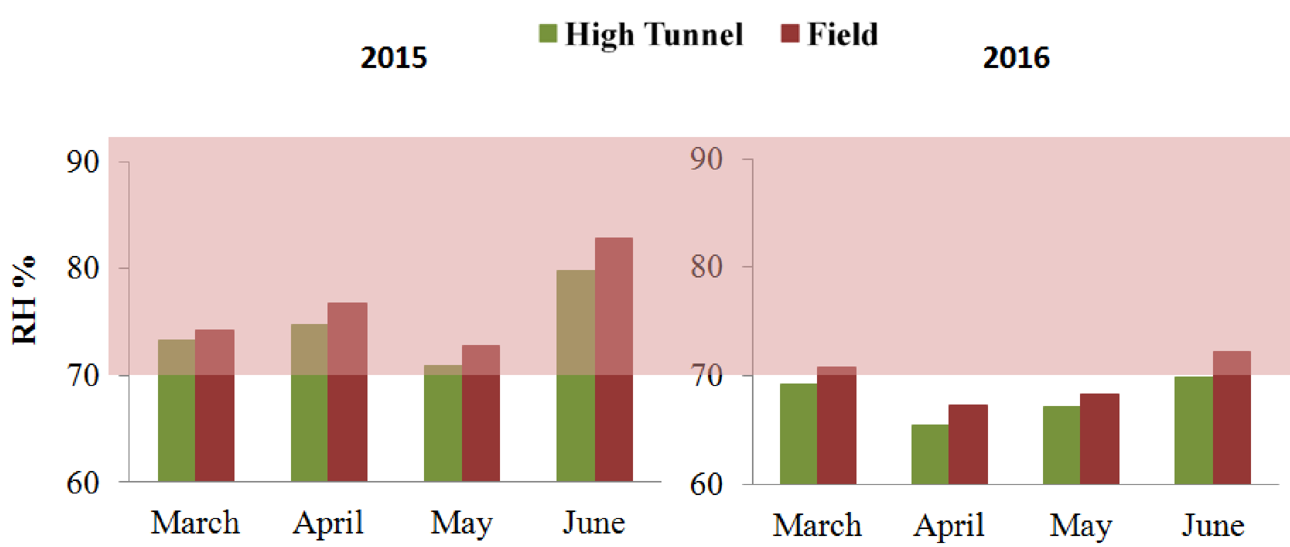

Fig. 2.8. Optimum Relative Humidity Levels for Lettuce Drop (*S. sclerotiorum*) Disease.

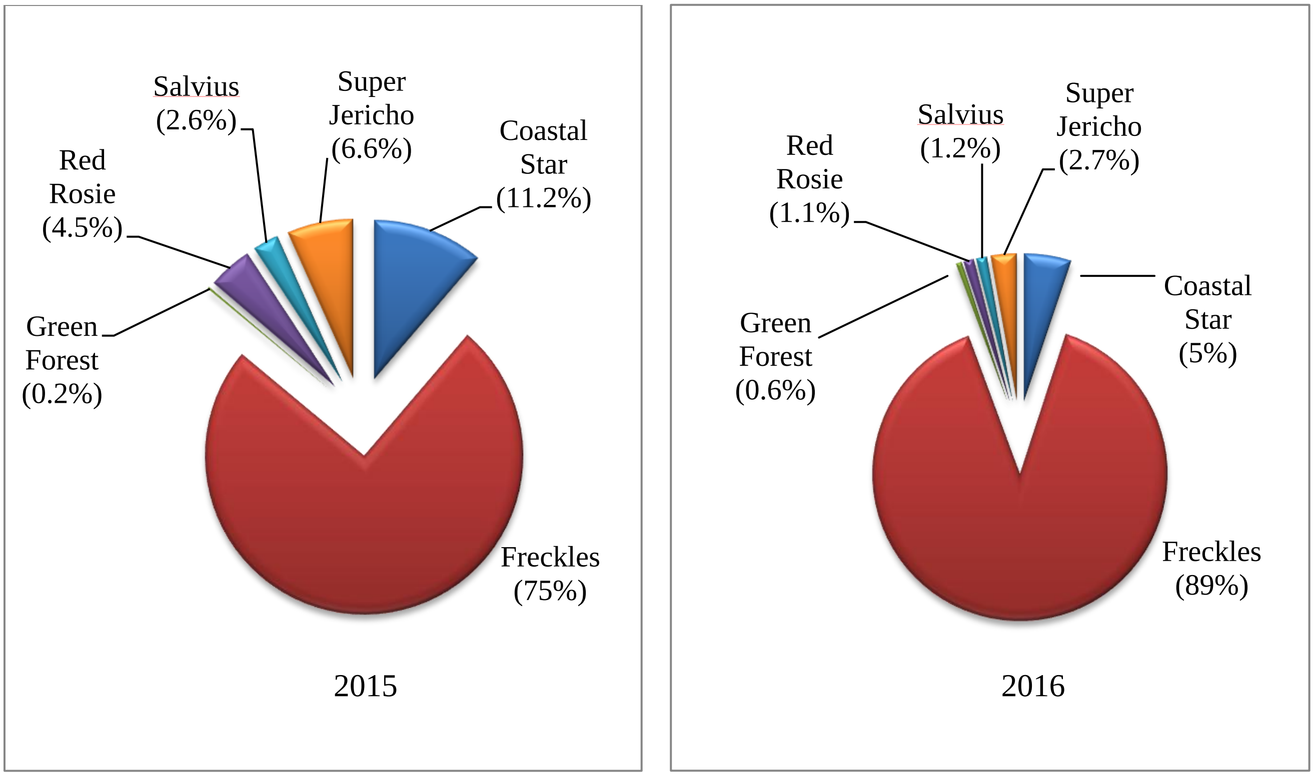

Fig. 2.9. Bolting Incidence Among Romaine Lettuce Cultivars.

Fig. 2.10. Lettuce Drop (*Sclerotinia sclerotiorum*) Infection.

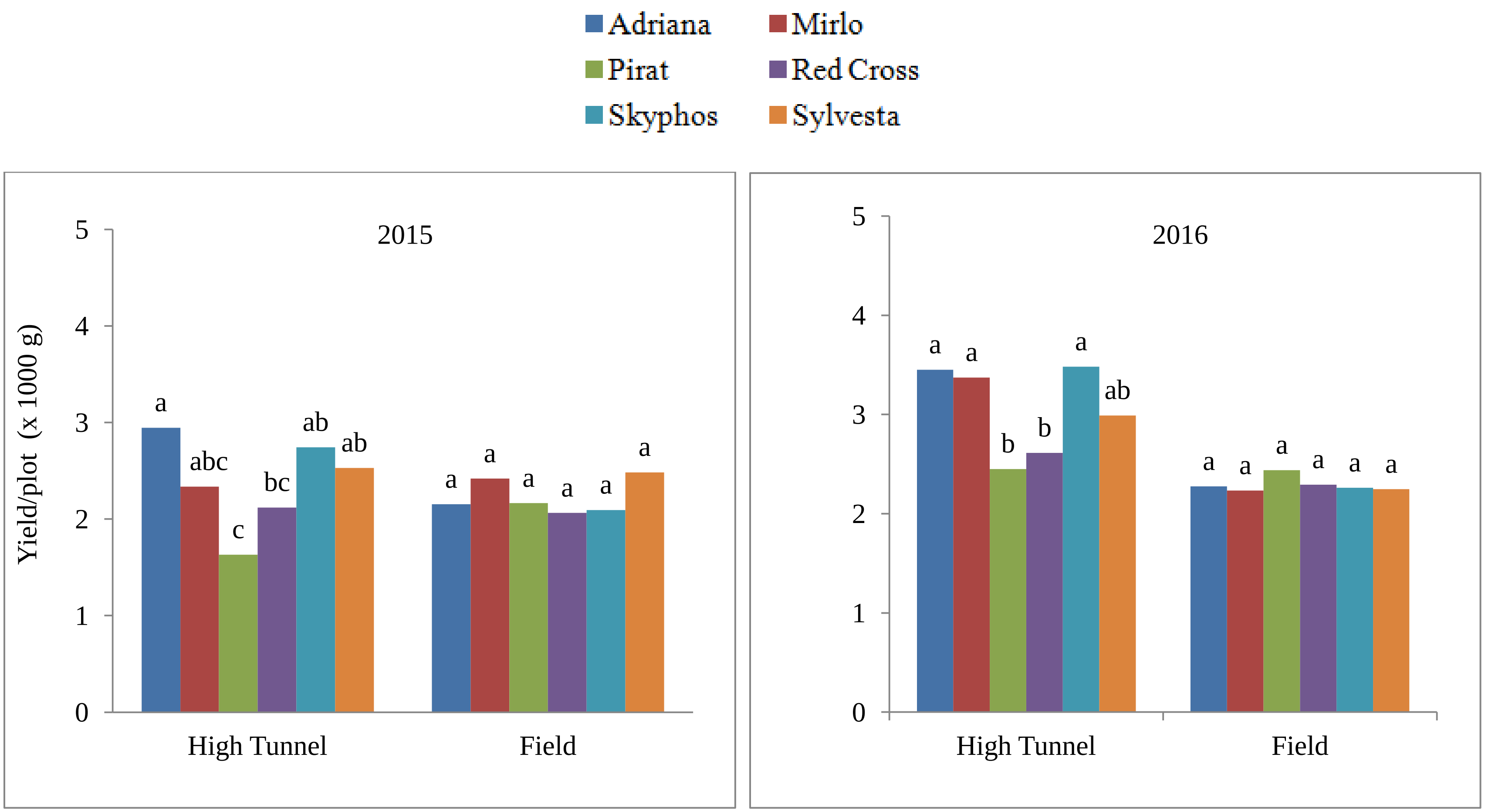

Fig. 2.11. Butterhead Lettuce Marketable Fresh Weight per Plot in 2015 and 2016 Among Growing Systems.

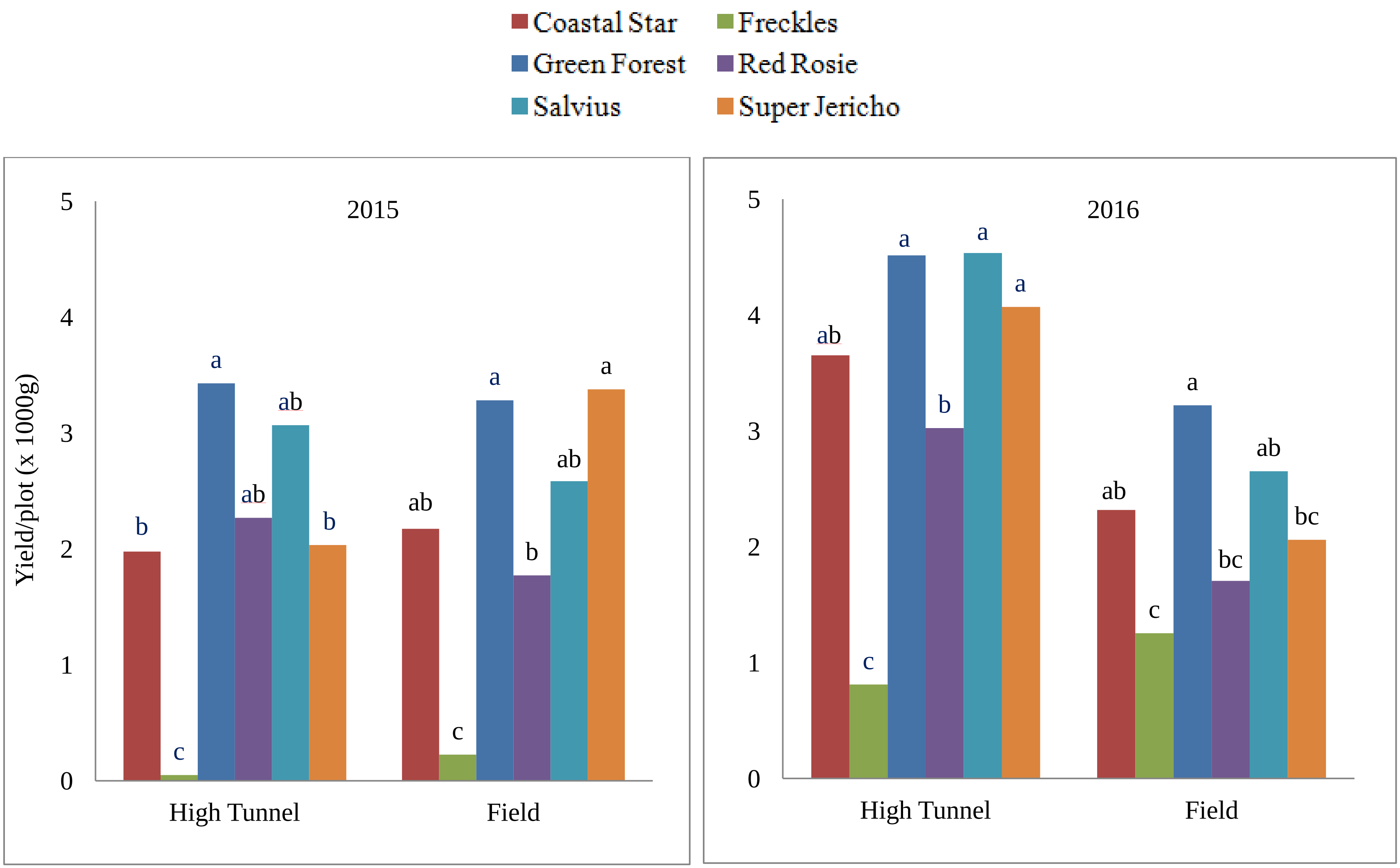

Fig. 2.12. Romaine Lettuce Marketable Fresh Weight per Plot in 2015 and 2016 Among Growing Systems.

Fig. 2.13: Six Butterhead Lettuce Cultivars Used for the Study. “Skyphos” (Top Left), “Mirlo” (Top Center), “Red Cross” (Top right), “Adriana” (Bottom Left), “Pirat” (Bottom Center), “Sylvesta” (Bottom Right).

Fig. 2.14: Six Romaine Lettuce Cultivars Used for the Study. “Freckles” (Top Left), “Red Rosie” (Top Center), “Super Jericho” (Top right), “Green Forest” (Bottom Left), “Coastal Star” (Bottom Center), “Salvius” (Bottom Right).

Table 2.1. Type of Fertilizers and Application Rate Applied to High Tunnel and the Field System, 2015 and 2016.

Year	Fertilizer Type	Availability	Rate	Rate
2015	Feathermeal (13N-0P-0K)	13% N	112 Kg $N.ha^{-1}$	100 Lb $N.A^{-1}$
	K_2SO_4 (0N-0P-50K)	50% K 17% S	34 Kg $K.ha^{-1}$ 11 Kg $S.ha^{-1}$	30 Lb $K.A^{-1}$ 10 Lb $S.A^{-1}$
	Boron	10% B	1 Kg $B.ha^{-1}$	1 Lb $B.A^{-1}$
2016	Feathermeal (13N-0P-0K)	13% N	112 Kg $N.ha^{-1}$	100 Lb $N.A^{-1}$
	K_2SO_4 (0N-0P-50K) (Field Only)	50% K 17% S	34 Kg $K.ha^{-1}$ 11 Kg $S.ha^{-1}$	30 Lb $K.A^{-1}$ 10 Lb $S.A^{-1}$
	$MgSO_4$ (High Tunnel only)	10% Mg 13% S	11 Kg $Mg.ha^{-1}$ 8.4 Kg $S.ha^{-1}$	10 Lb $Mg.A^{-1}$ 7.5 Lb $S.A^{-1}$
	Dolomitic Lime (Field only)	6% Mg	28 Kg $Mg.ha^{-1}$	25 Lb $Mg.A^{-1}$

Table 2.2 Seeding and Transplanting Dates in 2015 and 2016.

Year	Planting date	Seeding date	Transplanting date
2015	PD1	01/29/15	03/12/15
2015	PD2	02/19/15	04/02/15
2015	PD3	03/12/15	04/23/15
2016	PD1	01/28/16	03/03/16
2016	PD2	02/18/16	03/24/16
2016	PD3	03/10/16	04/14/16

Table 2.3. 2015 Average Monthly Micro-environmental Data.

Month	System	Air Temp (°C)			Soil Temp (°C)			RH %	PAR[z] (mol/m²/d)	LWC[y] (Min/d)
		Mean	Min	Max	Mean	Min	Max	Mean	Mean	Mean
March [x]	HT	15.1	8.7	21.8	17.2	14.9	19.6	73.2	21.0	5
	F	13.9	6.8	20.4	14.8	11.5	18.1	74.2	30.3	623
April	HT	18.5	12.4	24.5	20.2	18.0	22.3	74.7	23.0	2
	F	18.0	11.8	23.7	18.7	15.8	21.5	76.8	33.0	580
May	HT	22.6	15.0	30.4	25.2	22.3	28.3	71.0	33.1	9
	F	22.0	14.3	29.7	24.7	20.6	29.2	72.8	49.8	473
June [w]	HT	24.2	19.0	31.2	27.3	24.7	30.5	79.7	30.2	33
	F	23.4	18.5	30.1	26.0	22.2	30.7	82.8	45.0	628

[z] Photosynthetically active radiation [y] Leaf wetness counts

[x] March → 03/12/15 to 04/01/15 [w] June → 06/01/15 to 06/12/15

Table 2.4. 2016 Average Monthly Micro-environmental Data.

Month	System	Air Temp (°C)			Soil Temp (°C)			RH %	PAR[z] (mol/m²/d)	LWC[y] (Min/d)
		Mean	Min	Max	Mean	Min	Max	Mean	Mean	Mean
March [x]	HT	16.1	8.4	23.0	18.5	15.9	20.9	69.2	23.0	54
	F	15.1	15.1	15.1	16.1	12.8	19.1	70.8	35.7	437
April	HT	17.8	10.5	25.1	20.4	18.0	22.7	65.4	26.4	10
	F	16.9	16.9	16.9	19.1	16.0	21.8	67.2	44.9	401
May	HT	21.6	14.2	28.5	23.7	21.4	25.8	67.2	27.3	35
	F	21.0	21.0	21.0	23.5	20.1	26.7	68.3	47.0	232
June [w]	HT	25.8	19.0	33.3	28.3	25.7	30.9	69.8	28.8	24
	F	24.9	24.9	24.9	27.3	23.8	30.9	72.3	48.3	362

[z] Photosynthetically active radiation [y] Leaf wetness counts

[x] March → 03/03/16 to 04/01/16 [w] June → 06/01/16 to 06/10/16

Table 2.5. 2015 and 2016 Micro-environmental Data Among Planting Dates.

Year	Planting Date	Air Temp (°C)			Soil Temp (°C)			RH (%)	PAR (mol/m^2/d)	LWC (Min/d)
		Mean	Max	Min	Mean	Max	Min	Mean	Mean	Mean
2015 [z]	PD1	18.1 a[y]	24.7 a	11.2 a	19.7 a	22.6 a	16.7 a	73.4 a	31.6 a	11 a
	PD2	20.0 b	26.7 b	12.9 b	21.8 b	24.9 b	18.8 b	72.8 b	35.4 b	10 a
	PD3	21.8 c	29.2 c	14.6 c	24.4 c	28.0 c	21.0 c	73.0 c	39.9 c	11 a
2016	PD1	17.0 a	24.2 a	9.3 a	19.1 a	21.7 a	16.3 a	68.0 a	33.2 a	9 a
	PD2	18.5 b	25.3 b	11.2 b	20.8 b	23.3 b	18.1 b	68.7 b	34.3 a	9 a
	PD3	21.5 c	28.6 c	13.9 c	23.7 c	26.5 c	20.8 c	68.0 a	37.5 b	7 b

[z] Each year was analyzed separately.

[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).

Table 2.6. Comparison of Mean Butterhead Lettuce Yields and Days to Harvest Among Growing Systems.

Year	System	Marketable Yield (fresh wt./plot) (g)	Individual Marketable Head Fresh Wt. (g)	Individual Marketable Head Dry Wt. (g)	Marketable (%)	Bolting (%)	Tipburn (%)	Unders-ized (%)	Days to Harvest
2015[z]	High Tunnel	2384.7 a[y]	306.5 a	14.1 a	80.1 a	3.5 [x]	6.4 [x]	9.9 a	47 a
	Field	2229.6 a	277.8 a	15.3 a	94.9 a	<1 [x]	<1 [x]	4.4 a	49 a
2016	High Tunnel	3059.8 a	336.3 a	13.4 a	90.7 a	1.1 a	4.7 [x]	3.3 a	48 a
	Field	2291.4 b	252.1 b	14.1 a	92.6 a	1.1 a	<1 [x]	6.3 a	55 b

[z] Each year was analyzed separately.
[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).
[x] Data was not able to analyzed due to too few data points.

Table 2.7. Comparison of Mean Romaine Lettuce Yields and Days to Harvest Among Growing Systems.

Year	System	Marketable Yield (fresh wt./plot) (g)	Individual Marketable Head Fresh Wt. (g)	Individual Marketable Head Dry Wt. (g)	Marketable (%)	Bolting (%)	Tipburn (%)	Unders-ized (%)	Days to Harvest
2015[z]	High Tunnel	2137.5 b[y]	417.7 b	26.5 b	64.5 a	14.3 a	8.9 a	12.3 a	48 a
	Field	2235.7 b	445.8 b	28.6 b	64.8 a	12.5 a	2.8 a	19.9 a	52 a
2016	High Tunnel	3434.3 a	418.0 a	21.2 b	82.5 a	5.2 a	10.0 a	2.4 a	50 a
	Field	2201.5 b	282.9 b	23.6 b	80.8 a	10.8 a	1.5 a	6.9 a	57 b

[z] Each year was analyzed separately.
[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).

Table 2.8. Other Characteristics of Butterhead Lettuce Crop.

Year	Treatments	% Moisture	Head Length	Diameter
2015[z]	High Tunnel	95.2 a [y]	12.2 a	13.0 a
	Field	94.3 a	11.1 a	11.9 a
2016	High Tunnel	95.6 a	12.5 a	13.3 a
	Field	94.5 b	10.1 b	11.2 b
2015	PD1	95.0 a	12.3 a	13.2 a
	PD2	95.0 a	11.6 ab	12.0 b
	PD3	94.2 b	11.0 b	12.1 b
2016	PD1	94.9 a	12.1 a	14.6 a
	PD2	94.7 a	11.3 b	11.7 b
	PD3	95.6 a	10.7 b	10.5 c
2015	Adriana	94.3 ab	12.2 a	12.6 a
	Mirlo	94.9 ab	11.0 b	12.4 a
	Pirat	95.1 a	11.5 ab	12.1 a
	Red Cross	94.1 b	12.0 b	12.1 a
	Skyphos	94.9 ab	11.3 ab	12.7 a
	Sylvesta	95.2 a	11.9 ab	12.6 a
2016	Adriana	94.5 b	11.8 a	12.6 a
	Mirlo	95.0 ab	10.2 b	12.7 a
	Pirat	95.4 a	11.1 ab	11.1 b
	Red Cross	94.7 ab	11.9 a	12.3 a
	Skyphos	95.4 a	11.4 a	12.6 a
	Sylvesta	95.3 ab	11.6 a	12.4 a

[z] Each year was analyzed separately.

[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).

Table 2.9. Other Characteristics of Romaine Lettuce Crop.

Year	Treatments	% Moisture	Head Length	Diameter	Inner Stem Length	Number of Leaves
2015 [z]	High Tunnel	93.5 a [y]	24.0 a	10.6 a	7.9 a	31 a
	Field	93.2 a	20.6 a	8.8 a	6.4 a	26 a
2016	High Tunnel	94.2 a	26.1 a	10.7 a	7.3 a	32 a
	Field	91.5 b	20.3 b	9.1 b	6.0 a	33 a
2015	PD1	93.6 a	23.8 a	10.3 a	6.6 a	30 a
	PD2	91.7 b	19.1 a	8.6 a	6.2 a	26 a
	PD3	94.7 a	24.0 a	10.0 a	8.7 a	30 a
2016	PD1	92.6 a	25.4 a	12.1 a	6.6 a	35 a
	PD2	92.5 a	22.9 b	9.0 b	6.6 a	31 b
	PD3	93.5 a	21.3 c	8.6 b	6.9 a	31 b
2015	Coastal Star	93.1 ab	19.4 a	8.9 a	7.1 a	25 a
	Freckles	--- [x]	--- [x]	--- [x]	--- [x]	--- [x]
	Green Forest	93.9 a	23.3 a	9.9 a	7.6 a	27 a
	Red Rosie	92.6 b	23.3 a	8.9 a	6.6 a	31 a
	Salvius	93.9 a	22.4 a	9.9 a	7.9 a	29 a
	Super Jericho	93.3 ab	23.2 a	10.7 a	6.7 a	32 a
2016	Coastal Star	91.9 a	22.4 d	10.5 a	7.6 ab	30 c
	Freckles	93.9 b	19.3 e	8.2 b	5.9 cd	35 ab
	Green Forest	93.7 b	24.3 bc	11.2 a	7.9 ab	29 c
	Red Rosie	93.3 b	26.1 a	8.3 b	4.5 d	31 c
	Salvius	93.0 b	24.6 ab	10.2 a	7.9 a	32 bc
	Super Jericho	91.5 a	22.6 cd	11.0 a	6.2 bc	37 a

[z] Each year was analyzed separately.

[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).

[x] The cultivar 'Freckles' was removed from analysis due to too few data points.

Table 2.10. Percent Lettuce Drop (*Sclerotinia sclerotiorum*) Incidence for Butterhead and Romaine Lettuce.

Treatments	Butterhead		Treatments	Romaine	
	2015[z]	2016		2015[z]	2016
High Tunnel	6.4 a[y]	1.1 a	High Tunnel	9.2 a	3.7 a
Field	11.0 a	1.7 a	Field	9.6 a	2.4 a
PD1	18.2 a	2.3 a	PD1	21.0 a	3.6 a
PD2	6.9 a	1.7 a	PD2	6.2 ab	3.8 a
PD3	0.8 a	0.2 a	PD3	1.5 b	1.7 a
Adriana	9.1 a	1.7 a	Coastal Star	16.0 a	3.4 a
Mirlo	9.2 a	2.1 a	Freckles	8.9 a	2.5 a
Pirat	13.0 a	0.8 a	Green Forest	8.7 a	4.6 a
Red Cross	6.8 a	1.3 a	Red Rosie	9.2 a	3.4 a
Skyphos	6.4 a	0.4 a	Salvius	7.8 a	3.4 a
Sylvesta	7.1 a	2.1 a	Super Jericho	6.1 a	0.8 a

[z] Each year was analyzed separately.
[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).

Table 2.11. Comparison of Mean Butterhead and Romaine Lettuce Yields and Days to Harvest Among Planting Dates.

Type	Year	Planting Date	Marketable Yield (fresh wt./plot) (g)	Individual Marketable Head Fresh wt. (g)	Individual Marketable Head Dry wt. (g)	Market-able (%)	Bolting (%)	Tipburn (%)	Under-Sized (%)	Days to Harvest
BH[z]	2015[x]	PD1	2058.6 a[w]	309.8 a	15.4 a	86.4 a	0.6 a	0.6 a	12.4 a	56 a
		PD2	2760.0 a	327.1 a	15.2 a	88.8 a	4.17 a	3.1 a	2.1 a	46 b
		PD3	2102.9 a	239.5 b	13.4 a	88.1 a	1.46 a	5.2 a	5.2 a	42 c
BH	2016	PD1	3436.5 a	363.9 a	15.9 a	97.3 a	< 1[x]	< 1[x]	2.5 a	55 a
		PD2	2472.3 b	263.5 b	13.9 b	96.7 a	< 1	0.1	2.5 a	51 ab
		PD3	2117.9 b	255.1 b	11.4 c	81.0 b	3.4	6.3	9.4 a	49 b
RM[y]	2015[x]	PD1	2217.8 a	560.8 a	33.5 a	66.2 a	6.5 a	10.3 a	16.9 a	59 a
		PD2	1594.9 a	347.1 b	28.2 a	55.3 a	18.5 a	3.1 a	23.1 a	49 b
		PD3	2747.1 a	387.3 b	21.0 b	72.8 a	14.7 a	4.2 a	8.2 b	42 c
RM	2016	PD1	3859.8 a	447.4 a	26.3 a	88.9 a	1.5 a	5.4 a	4.2 a	61 a
		PD2	2539.6 b	310.1 b	22.7 b	85.2 a	5.9 a	6.4 a	2.5 a	54 b
		PD3	2054.3 b	293.9 b	18.1 c	70.8 b	16.6 b	5.5 a	7.1 a	46 c

[z] BH =Butterhead lettuce
[y] RM = Romaine lettuce
[x] Each year was analyzed separately.
[w] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).
[v] Data was not able to analyzed due to too few data points.

Table 2.12. Marketable Fresh Weight per Plot Among Planting Dates for Each System.

Year	Type	System	Planting Date		
			PD1	PD2	PD3
2015[z]	Butterhead	High Tunnel	1972.3 a[y]	2987.0 a	2194.8 a
		Field	2144.8 a	2533.1 a	2011.1 a
	Romaine	High Tunnel	2340.4 a	1343.3 a	2728.8 a
		Field	2095.3 a	1846.5 a	2765.3 a
2016	Butterhead	High Tunnel	4006.2 a	2985.2 b	2118.1 c
		Field	2866.9 a	1959.4 b	2047.8 b
	Romaine	High Tunnel	4710.1 a	3241.2 b	2351.7 c
		Field	3009.5 a	1838.0 b	1756.9 b

[z] Each year was analyzed separately.
[y] Values followed by the same letter are not significantly different within a row for each year, according to Tukey's mean separation test ($P \leq 0.05$).

Table 2.13. Marketable Fresh Weight per Plot Among Growing Systems for Each Planting Date.

Year	Type	System	Planting Date		
			PD1	PD2	PD3
2015[z]	Butterhead	High Tunnel	1972.3 a[y]	2987.0 a	2194.8 a
		Field	2144.8 a	2533.1 a	2011.1 a
	Romaine	High Tunnel	2340.4 a	1343.3 a	2728.8 a
		Field	2095.3 a	1846.5 a	2765.3 a
2016	Butterhead	High Tunnel	4006.2 a	2985.2 a	2118.1 a
		Field	2866.9 b	1959.4 b	2047.8 a
	Romaine	High Tunnel	4710.1 a	3241.2 a	2351.7 a
		Field	3009.5 b	1838.0 b	1756.9 a

[z] Each year was analyzed separately.
[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).

Table 2.14. Comparison of Mean Butterhead Lettuce Yields and Days to Harvest among Cultivars.

Year	Cultivar	Marketable Yield (fresh wt./plot) (g)	Individual Marketable Head Fresh wt. (g)	Individual Marketable Head Dry wt. (g)	Market-able (%)	Bolting (%)	Tipburn (%)	Under-Sized (%)	Days to Harvest
2015[z]	Adriana	2550.4 a[y]	305.2 a	16.7 a	91.7 ab	1.2 a	0.8 [x]	6.2 a	48 abc
	Mirlo	2377.8 ab	295.9 a	15.0 abc	91.3 ab	2.5 a	0.8	4.1 a	48 ab
	Pirat	1897.9 b	276.5 a	13.0 c	78.9 b	5.4 a	4.6	11.6 a	47 bc
	Red Cross	2091.7 ab	285.2 a	16.1 ab	82.9 ab	0.4 a	11.6	4.6 a	49 a
	Skyphos	2418.3 ab	283.2 a	13.3 bc	94.5 a	0.4 a	0	5.0 a	49 ab
	Sylvesta	2507.0 a	306.8 a	13.9 abc	87.5 ab	2.5 a	0	10.0 a	46 c
2016	Adriana	2863.0 ab	311.6 a	16.5 a	91.7 ab	2.5 [x]	1.3 [x]	4.6 a	52 ab
	Mirlo	2803.3 ab	305.1 a	14.4 b	93.3 ab	0	0	6.7 a	54 a
	Pirat	2445.3 b	280.4 a	12.1 c	86.2 b	1.7	9.2	2.5 a	49 b
	Red Cross	2452.8 b	281.8 a	13.5 bc	88.2 ab	0.4	3.8	7.6 a	52 a
	Skyphos	2870.9 a	301.1 a	12.4 c	97.5 a	0	0	2.5 a	53 a
	Sylvesta	2618.4 ab	285.1 a	13.4 bc	92.9 ab	2.1	0	5.0 a	49 b

[z] Each year was analyzed separately.
[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).
[x] Data was not able to analyzed due to too few data points.

Table 2.15. Comparison of Mean Romaine Lettuce Yields and Days to Harvest among Cultivars.

Year	Cultivar	Marketable Yield (fresh wt./plot)(g)	Individual Marketable Head Fresh wt. (g)	Individual Marketable Head Dry wt. (g)	Marketable (%)	Bolting (%)	Tipburn (%)	Under-Sized (%)	Days to Harvest
2015[z]	Coastal Star	2075.0 ab[y]	443.6 a	29.9 a	66.8 a	15.0 b	0 a	17.1 a	49 a
	Freckles	136.7 c	--- [x]	--- [x]	20.4 b	39.4 a	28.8 a	11.5 a	46 b
	Green Forest	3355.9 a	461.7 a	27.7 a	83.5 a	0.4 c	0.9 a	15.2 a	50 a
	Red Rosie	2020.1 b	320.6 a	22.8 b	73.3 a	8.3 bc	0 a	18.3 a	51 a
	Salvius	2825.9 ab	463.6 a	26.8 ab	74.6 a	6.0 bc	0.4 a	19.0 a	50 a
	Super Jericho	2705.8 ab	469.2 b	30.6 a	68.0 a	11.3 bc	5.6 a	15.2 a	50 a
2016	Coastal Star	2984.8 bc	340.1 bc	25.8 a	88.7 a	6.7 b	0.4 a	4.2 a	53 ab
	Freckles	1033.0 d	302.4 cd	13.1 b	35.3 b	32.8 a	25.6 b	6.7 a	52 b
	Green Forest	3866.3 a	441.7 a	27.3 a	90.8 a	0.8 b	4.6 a	3.3 a	55 a
	Red Rosie	2365.2 c	271.0 d	16.5 b	92.8 a	1.7 b	1.3 a	4.2 a	53 ab
	Salvius	3592.9 ab	397.1 ab	25.4 a	94.9 a	2.1 b	0.4 a	2.6 a	53 ab
	Super Jericho	3065.3 bc	350.4 bc	26.4 a	87.4 a	3.8 b	2.1 a	6.7 a	54 a

[z] Each year was analyzed separately.
[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).
[x] The cultivar Freckles was removed from analysis due to too few data points.

Table 2.16. Marketable Fresh Weight per Plot Among Butterhead Cultivars for Each Growing System.

Year	System	Cultivars					
		Adriana	Mirlo	Pirat	Red Cross	Skyphos	Sylvesta
2015[z]	High Tunnel	2947 a[y]	2337 a	1632 a	2120 a	2743 a	2529 a
	Field	2154 a	2418 a	2164 a	2063 a	2094 a	2485 a
2016	High Tunnel	3451 a	3373 a	2451 a	2612 a	3481 a	2990 a
	Field	2275 b	2233 b	2439 a	2293 a	2261 b	2247 b

[z] Each year was analyzed separately.
[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).

Table 2.17. Marketable Fresh Weight per Plot Among Romaine Cultivars for Each Growing System.

Year	System	Cultivars					
		Coastal Star	Freckles	Green Forest	Red Rosie	Salvius	Super Jericho
2015[z]	High Tunnel	1977 a[y]	49 a	3429 a	2269 a	3067 a	2034 a
	Field	2173 a	225 a	3283 a	1771 a	2585 a	3377 b
2016	High Tunnel	3652 a	812 a	4513 a	3024 a	4535 a	4070 a
	Field	2318 b	1254 a	3219 b	1706 b	2651 b	2060 b

[z] Each year was analyzed separately.
[y] Values followed by the same letter are not significantly different within a column for each year, according to Tukey's mean separation test ($P \leq 0.05$).

CHAPTER 3

CONSUMER LETTUCE PREFERENCES AND TASTE EVALUATION

Materials and Methods

A Southern SARE grant was funded to conduct a consumer and taste survey of lettuce we grew in an organic high tunnel compared to the field experiment (see Chap. 2). The goal of thise survey was to identify the purchasing habits, visual preferences and taste ratings of locally grown head lettuce among shoppers at a local farmers market. Multiple lettuce cultivars were represented in the visual and taste evaluation portion of the study. These cultivarswere selected based on their strong performance (i.e., highest marketable yields) in the concurrent production research trial or their unique visual appeal.

‘The Athens Farmers Market’ located in Athens, GA was the location of the study. The Athens Farmers Market is a not-for-profit corporation which is operated in accordance with state, county and local laws, for the benefit of farmers and consumers alike. Its mission is to provide a marketplace for food grown locally using sustainable farming methods and for locally produced hand crafted goods and prepared foods. The Athens Farmers Market’s also includes education about and support of local sustainable agriculture. Approximately, 1,000 to 1,500 (personal communication) people visit the Athens Farmers Market every Saturday morning (open 8am-noon) from early April to mid-December.

Prior to the writing the survey instrument, research team members conducted informal investigations at multiple farmers markets in the Athens and Atlanta, GA area to assess the volume of customers (i.e. potential survey participants), the type of products offered for sale, the typical price range and types of locally-grown lettuce for sale, etc. In addition, several months prior to administering the survey the following actions were completed. A list of study questions were created based on our goals and the preliminary farmers market assessment. The opinions of several people including faculty, students and statisticians were solicited about the clarity and analytical merit of the draft survey questions. Modifications were made as suggested. An application was submitted to the the Athens Farmers Market to conduct the survey and utilize space at two Saturday markets which was approved by their Board. The dates chosen were 7 May and 14 May. These dates were anticipated to overlap with peak lettuce harvests from our high tunnel experiment (see Chap. 2). Team leaders were passed a University of Georgia (UGA) approved training module related to social and behavioral science and ethics. The survey instrument, a recruitment script and a participant consent form were reviewed by the UGA Institutional Review Board (IRB) and granted an exempt review approval (*DHHS-exemption # 6 related to taste and food quality evaluation and consumer acceptance studies).

Two types of organically grown head lettuce, butterhead and romaine, were selected for the study. All lettuce was grown on USDA certified organic land at the University of Georgia, Horticulture Research Station located in Watkinsville, GA. The top three performing cultivars (i.e., highest marketable yields) of both butterhead and romaine cultivars from our 2015 spring lettuce trial were selected for inclusion. Butterhead lettuce cultivars included: "Adriana" (BH-A), "Sylvesta" (BH-B), and "Skyphos" (BH-C). Romaine lettuce cultivars included: "Green Forest" (RM-A), "Salvius" (RM-B), and "Super Jericho" (RM-C). The butterhead cultivar "Red Cross" (BH-D) and the romaine cultivar "Red Rosie" (RM-D) were included as a 4th cultivar for each lettuce type due to their unique red leaf tissue color. All the samples were harvested from the high tunnel growing system, planting date two treatment from our 2016 spring lettuce study (see Chap. 2).

Lettuce was harvested 2-4 days before the survey date. Approximately 10-12 high quality, marketable lettuce heads were selected and stored in a walk-in refrigerator at just above 0^{o}C. The day before the survey, lettuce heads broken down, cleaned and chopped into bite-sized pieces, one sample at a time in a clean kitchen. Lettuce leaves were rinsed with clean water and then submerged in a 1000 ppm SaniDate 5.0 (BioSafe Systems LLC, Hartford, CT) disinfectant solution for a minimum of 45 seconds. Then, excess solution was drained using a salad spinner. Batch by batch, leaves were cut into approximately 1cm wide pieces. Pre-cut lettuce were stored in labeled ~15 L (4 gallon) plastic bags and in a plastic cooler at 0-2^{o}C and put back into the walk-in refrigerator. On the day of the survey, lettuce samples were transported to the Athens Farmers Market in the same coolers with the addition of 4-5 frozen ice packs and 1 bag of ice per cooler in a covered vehicle.

Volunteer survey participants were solicited by project staff in person with a verbal request based on the approved recruitment script. Only individuals greater than 18 years old were allowed to participate. The survey consent agreement was reviewed together before beginning the actual survey. First, all participants were asked ten general questions about their consumer and buying preferences regarding lettuce (i.e. page 1 of the survey see appendix). Second, participants were randomly assigned to evaluate either butterhead or romaine lettuce (i.e. page 2 of the survey see appendix). Each participant was given four, lettuce samples on separate paper plates labeled as “A”, “B”, “C”, and “D”. They were asked to rank each of their four lettuce samples on a Likert scale of 1 to 5 for sweetness (very sweet to not sweet), bitterness (very bitter to not bitter), overall taste, and crunchy texture. Next, participants were asked to rate on a Likert scale of 1 to 5, four full-sized lettuce heads (butterhead or romaine) which had corresponding labels of “A”, “B”, “C”, and “D” for color and visual appearance. And lastly, participants were asked to provide an overall rating of each lettuce sample they evaluated based on taste, texture, and color. Selected demographic information was also asked including: age, household size and annual household income. A $5 token, which could be used as cash at the Athens Farmers Market was given to each participant.

One-hundred and twenty-six surveys were completed on 7 May 2016 which surpassed our goal of 110 completed surveys. Out of those 126 surveys, 60 focused on butterhead lettuce and 62 focused on romaine lettuce. Four surveys had incomplete data on the second page therefore, we used only the information on the first page of those four surveys which were questions about general lettuce buying and consumer preferences.

Data about demographics and general lettuce buying and consumer preferences (questions #1-10 and 11-12) were combined for the butterhead and romaine lettuce surveys. The six questions that evaluated taste and visual appearance (questions #i-vi) were analyzed separately for butterhead and romaine lettuce. The mean and standard deviation were calculated for questions with quantitative categories (e.g., questions #1, 2, 3, and 5) (Table 3.1) (SAS statistical software program, SAS Institute, Cary, NC; used, PROC means in SAS). The frequency and percentage of each category was calculated for questions with qualitative choices (e.g. questions #4, 6, 7, 8, and 9) (Table 3.2) (Used, PROC freq in SAS). And the mean was calculated for each category associated with question #10 that asked participants to rank which factors are most important when they consider buying lettuce on a scale of 1 to 6 (with 1 = most important and 6 = least important). Therefore a mean close to 1 was considered a stronger factor, a mean close to the 6 was considered a weaker factor when buying lettuce (Table 3.3).

The frequency and percentage of total responses was generated for each qualitative taste or visual assessment question (#i-vi) including indicators of sweetness, bitterness, overall taste, crunchy texture, color and overall rating for each assigned sample (A, B, C, and D) (Tables 3.4 and 3.5) (Used, PROC freq in SAS). Paired T-tests were used to identify differences among consumer preferences within the butterhead group and within the romaine group (Table 3.4 and Table 3.5) (Used, PROC ttest in SAS). Frequencies were also generated for responses to selected questions by demographic group (questions # 1, 11 and 12) (Table 3.6) (Used, PROC freq in SAS).

Fig. 3.1. Lettuce Consumer and Taste Survey at ‘The Athens Farmers Market’ on 7 May 2016 (Athens, Georgia).

Results

Table 3.1. Demographic Characteristics of Survey Participants.

Category	Frequency	% Responses
Age (years)		n = 125
18 - 25	58	46
26 - 35	27	22
36 - 50	19	15
51 - 65	12	10
>65	9	7
Household Size		n = 122
0	2	2
1	22	18
2	50	41
3	21	17
4	19	16
5+	8	6
Household Income ($USD)		n = 122
< 15,000	27	22
15,000 - 34,999	14	12
35,000 - 74,999	33	27
75,000 - 149,999	21	17
150,000 - 200,000	6	5
>200,000	5	4
Don't Know	5	4
Prefer not to answer	11	9

Table 3.2. Lettuce Buying Practices of Survey Participants.

Question	Mean	SD
How many times do you eat lettuce per week?	3 to 4	1.9
How many times do you buy lettuce per week?	1 to 2	0.7
When you buy lettuce what percentage is organic?	50 to 99%	39.3

Table 3.3. Answers to Selected Qualitative Questions About Lettuce Purchases.

Question	Answer Choice	Frequ-ency	% Responses
From where do you buy lettuce	National Supermarkets	91	73%
	Farmers Market	72	58%
	Specialty Grocery (Earthfare, Fresh Market, etc.)	47	38%
	Other Places	25	20%
	Retail Chains (Walmart, Target, etc.)	10	8%
What are the most common ways you eat lettuce	Salads	117	94%
	Sandwich Topping	80	64%
	Lettuce Wraps	31	25%
	Garnish	15	12%
	Other Methods	13	10%
What size of lettuce do you prefer to buy	Baby Salad/Mesclun Mix	66	53%
	Small Heads	56	45%
	Large Heads	48	38%
	Pre-cut Leaves	31	25%
	Other Ways	2	2%
What type of lettuce do you prefer most	Romaine	46	47%
	Butterhead/Bibb/Boston	23	23%
	Leaf Lettuce	21	22%
	Other Lettuce Types	4	4%
	Iceberg	3	3%
How much would you pay for a head of lettuce	$3.00 - 3.99	36	30%
	$2.00–2.99	35	29%
	Current Market Price	30	25%
	$1.00–1.99	13	11%
	I don’t buy organic Lettuce	5	4%

Table 3.4. Factors that Survey Participants Consider When Buying Lettuce.

Rank	**Factor**
1[a]	Freshness
2	Taste
3	Visual Appearance
4	Price
5	Organic
6	Local

[a] Scale 1 to 6 where 1 = most important and 6 = least important

Table 3.5. Butterhead Lettuce Taste and Visual Evaluations by Survey Participants

Category	Cultivar	Most Frequent Descriptor Category	T-Test
Sweetness	Adriana	Slightly Sweet	b[z]
	Sylvesta	Sweet	a
	Skyphos	Sweet	a
	Red Cross	Not Sweet	b
Bitterness	Adriana	Semi/Not Bitter[y]	a
	Sylvesta	Not Bitter	b
	Skyphos	Not Bitter	b
	Red Cross	Not Bitter	a
Overall Taste	Adriana	Prefer	b
	Sylvesta	Strongly Prefer/Prefer	a
	Skyphos	Prefer	a
	Red Cross	Neutral	b
Crunchy Texture	Adriana	Prefer	b
	Sylvesta	Prefer	a
	Skyphos	Prefer	a
	Red Cross	Neutral	ab
Color	Adriana	Strongly Prefer	a
	Sylvesta	Prefer	b
	Skyphos	Prefer	b
	Red Cross	Strongly Prefer	ab
Overall Rating	Adriana	Prefer	b
	Sylvesta	Strongly Prefer	a
	Skyphos	Prefer/Neutral	ab
	Red Cross	Prefer	b

[z] Values followed by the same letter are not significantly different within a column for each category, according to paired T-test when $P \leq 0.05$.
[y] When two categories are tied both categories were listed.

Table 3.6. Romaine Lettuce Taste and Visual Evaluations by Survey Participants.

Category	**Cultivar**	**Most Frequent Descriptor Category**	**T-Test**
Sweetness	Green Forest	Slightly Sweet	b[z]
	Salvius	Not Sweet	b
	Super Jericho	Sweet	a
	Red Rosie	Not Sweet	ab
Bitterness	Green Forest	Not Bitter	a
	Salvius	Not Bitter	b
	Super Jericho	Not Bitter	c
	Red Rosie	Slightly Bitter	b
Overall Taste	Green Forest	Prefer	a
	Salvius	Prefer	a
	Super Jericho	Prefer	a
	Red Rosie	Strongly Prefer	a
Crunchy Texture	Green Forest	Prefer	a
	Salvius	Neutral	a
	Super Jericho	Prefer	a
	Red Rosie	Prefer	a
Color	Green Forest	Prefer	b
	Salvius	Strongly Prefer	a
	Super Jericho	Neutral	b
	Red Rosie	Strongly Prefer	ab
Overall Rating	Green Forest	Prefer	a
	Salvius	Prefer	a
	Super Jericho	Prefer	a
	Red Rosie	Prefer	a

[z] Values followed by the same letter are not significantly different within a column for each category, according to paired T-test when $P \leq 0.05$.

Table 3.7. Responses to Selected Questions by Demographic Group.

Demographic Category	How Many Times Do You Eat Lettuce per Week	How Many Times Do You Buy per Week	When You Buy Lettuce What Percentage is Organic	How Much Would You Pay for a Head of Organic Lettuce	What Type of Lettuce Do You Prefer the Most
Age (Years)					
18 - 25	3-4	<1	0%	$2.00-2.99	Romaine
26 - 35	3-4	1-2	50-99% or Never buy [y]	$3.00-3.99	Romaine
36 - 50	3-4	1-2	Never buy	Mkt. price [z]	Romaine
51 - 65	3-4	1-2	100%	Mkt. price	Romaine
>65	5-6	<1	1-49%	$3.00-3.99	Romaine
Number of People in the Household that Eat Lettuce					
0	1-2	1-2	Never buy	$3.00-3.99	Romaine
1	<1, 1-2, 3-4	<1	50-99%	Mkt. price	Romaine
2	3-4	1-2	Never buy	$3.00-3.99	Romaine
3	3-4	1-2	100%	$3.00-3.99	Romaine
4	3-4	1-2	100%	$2.00-2.99 or Mkt. pr	Romaine
5+	1-2, 3-4, 5-6	<1, 1-2	1-49%	$3.00-3.99 or Mkt. pr	Romaine

Household Income ($USD)					
< 15,000	3-4	1-2	0%	$2.00-2.99	Romaine
15,000 - 34,999	3-4	<1	50-99%	$2.00-2.99, $3.-3.99	Romaine
35,000 - 74,999	3-4	1-2	I never buy lettuce	$3.00-3.99	Romaine
75,000 - 149,999	3-4	1-2	0% or Never buy	Mkt. price	Romaine
150,000 - 200,000	5-6	<1	1-49% or Never buy	$3.00-3.99	Butterhead/Bibb/Boston Romaine [x]
>200,000	3-4	<1	1-49%	$2.00-2.99	Butterhead/Bibb/Boston
Don't Know	1-2, 5-6	<1	100%	Mkt. price	Leaf lettuce Butterhead/Bibb/Boston Romaine Iceberg
Prefer not to answer	1-2	<1	1-49% or 50-99%	$1.00-1.99	Butterhead/Bibb/Boston , Romaine
Overall	3-4	1-2	I never buy lettuce	$3.00-3.99	Romaine

[z] Mkt. price = Willing to pay the current market price
[y] Never buy = I never buy lettuce
[x] When two categories are tied both categories were listed.

APPENDIX

Organic Lettuce Research Survey

SOUTHERN SARE Sustainable Agriculture Research & Education

The University of Georgia

ORGANIC LETTUCE RESEARCH SURVEY

1. What is your age group? (Select one)
   ☐ 18-25yrs ☐ 26-35yrs ☐ 36-50yrs ☐ 51-65yrs ☐ >65yrs

2. How many times do you eat lettuce per week? (Select one)
   ☐ <1 ☐ 1-2 ☐ 3-4 ☐ 5-6 ☐ Daily

3. How many times do you buy lettuce per week? (Select one)
   ☐ <1 ☐ 1-2 ☐ 3-4 ☐ 5-6 ☐ Daily

4. Where do you buy lettuce? (Select all that apply)
   ☐ Farmers Market ☐ National Supermarkets (Kroger, Publix, etc.)
   ☐ Retail Chains (Walmart, Target, etc.) ☐ Specialty Grocery (Earthfare, Fresh Market, etc.)
   ☐ Other____________________ (please specify)

5. When you buy lettuce, what percentage is organic? (Select one)
   ☐ 0% ☐ 1-33% ☐ 34-66% ☐ 67-99% ☐ 100%

6. What are the most common ways you eat lettuce? (Select all that apply)
   ☐ Sandwich Topping ☐ Salads ☐ Lettuce Wraps ☐ Garnish
   ☐ Other ____________________(please specify)

7. How much would you pay for a head of organic lettuce? (Select one)
   ☐ $1.00-1.99 ☐ $2.00-2.99 ☐ $3.00-3.99 ☐ Current Market Price
   ☐ I do not buy organic lettuce

8. What size of lettuce do you prefer to buy? (Select all that apply)
   ☐ Large Heads ☐ Small Heads ☐ Baby Salad/Mesclun Mix ☐ Pre-cut Leaves
   ☐ Other ____________________(please specify)

9. What type of lettuce do you prefer most? (Select one)
   ☐ Leaf Lettuce ☐ Butterhead/Bibb/Boston ☐ Romaine ☐ Iceberg
   ☐ Other ____________________(please specify)

10. Please rank the importance of the following factors you consider when buying lettuce:
    (Scale 1 to 6 when 1 = most important and 6 = least important)

    ____ Visual Appearance
    ____ Taste
    ____ Organic
    ____ Price
    ____ Freshness
    ____ Local

1 of 2

BH or RM

Please rate the lettuce samples you have been given according to the following descriptors:

i. Sweetness (Select one)

Sample	very sweet	sweet	semi-sweet	slightly sweet	not sweet
A					
B					
C					
D					

ii. Bitterness (Select one)

Sample	very bitter	bitter	semi-bitter	slightly bitter	not bitter
A					
B					
C					
D					

Please rate the lettuce samples you have been given according to the following scale:
1 = Strongly Prefer, 2 = Prefer, 3 = Neutral, 4 = Dislike, 5 = Strongly Dislike

iii. Overall Taste

Sample	1	2	3	4	5
A					
B					
C					
D					

iv. Crunchy Texture

Sample	1	2	3	4	5
A					
B					
C					
D					

v. Color (Whole heads*)

Sample	1	2	3	4	5
A					
B					
C					
D					

vi. Overall Rating (Taste, texture & color)

Sample	1	2	3	4	5
A					
B					
C					
D					

11. What is the number of people in your household that eat lettuce (including yourself)?
☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5+

12. Which best describes your annual household income?
☐ < $15,000 ☐ $15,000–34,999 ☐ $35,000–74,999 ☐ $75,000–149,999
☐ $150,000–200,000 ☐ > $200,000 ☐ Don't know ☐ Prefer not to answer

Thank you very much for participating! Please return your survey to project staff and receive tokens that can be used at the farmers market.

If you have any questions or concerns about this research project please contact: TC Jayalath, UGA-Dept. of Horticulture, 1111 Plant Sciences Bldg., Athens, GA 30602 (*tcjay@uga.edu*, (706) 542-2471) or the UGA-IRB office at (*irb@uga.edu*, (706) 542-3199)

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