University of Nevada, Reno

Studies of high desert hoop house agriculture: Exploring new techniques for produce production and the potential benefits and drawbacks of hoop house use.

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Abstract:

Produce in northern Nevada is successfully grown within hoop houses. Unfortunately, few studies have tested the benefits or drawbacks of hoop house use. Ultraviolet (UV) radiation is known to be reduced in hoop house environments, potentially limiting production of secondary compounds that benefit human nutrition. In hoop houses, supplemental UV radiation could be a useful and cost effective way to improve product quality and end-consumer health. In one study, supplemental UV treatment was applied to *Lactuca sativa* (lettuce) in greenhouses and hoop houses at 64.4±0.9 J m^{-2} min^{-1} for varying durations. Leaf samples from plants grown with supplemental UV treatment were then compared to samples from plants grown without supplementation. In the greenhouse, no significant difference in antioxidant content or specific leaf area (SLA) was found. In hoop houses, a roughly three-fold increase in tocopherol content was found with 120 minutes of supplemental UV treatment twice a day, but no other plant response variables that were measured were significant. These conflicting results between greenhouse and hoop house experiments suggest that further study is needed in the hoop house environment to determine if other factors interact with supplemental UV treatment to affect tocopherol production. Nonetheless, we concluded that, at this time, no recommendations can be made to local farmers to use supplemental UV radiation to increase *L. sativa* quality.

In addition to the supplemental UV experiments, four studies were completed in hoop houses and nearby uncovered plots to investigate certain aspects of hoop house agriculture. The first study documented environmental data from both hoop houses and uncovered plots, and we concluded hoop houses created a microclimate with greater air temperature and soil water content. The second study tested the effect of planting date on the antioxidant content of winter greens, *Eruca sativa* (arugula) and *Spinacia oleracea* (spinach), and we concluded that planting

date does not have a significant effect on antioxidant content. However, tocopherol content in spinach and ascorbic acid content in both arugula and spinach increased over winter from December to March regardless of when the greens were planted in the fall. The third and fourth studies tested consumer preference for three varieties of heirloom *Lycopersicon lycopersicum* (tomato) called Black Cherry, New Yorker, and Pink Berkeley Tie Dye (PBTD). The third study tested consumer preference among these three varieties, and we concluded that Black Cherry and New Yorker tomatoes were preferred equally over PBTD. The fourth study tested consumer preference between samples harvested from an early planting date versus samples harvested from a later planting date of the same variety. We concluded that early planting of New Yorker and PBTD tomatoes produce more preferred fruit and that Black Cherry tomatoes have no major preference based on planting date.

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Chapter 1: General introduction

Agriculture in northern Nevadan can be a difficult endeavor, as the frost-free growing season in the area is only up to 90 days (Nevada Department of Agriculture, 1976). Furthermore, temperature during the summer fluctuates between 32 ºC during the day and 24 ºC during the night, and temperature during the winter fluctuates between 12 ºC during the day and 0 ºC during the night. Nevada has a dry climate all year long, with an annual average rainfall of 0.3 m, but rainfall varies widely throughout the state (EPA, 2016). Soil quality in Nevada is variable and often challenging to work with because high salt concentrations and low organic matter make it difficult to cultivate produce (Hefner, 2014). Range animals and field crops dominate the agricultural landscape, as both survive and sometimes thrive in the harsh Nevadan climate. Produce agriculture, however, only accounts for 14% of the gross commodity value of Nevada, and only 13% of the total cash receipts (Governor's Office of Economic Development, 2013).

In response to the environmental challenges of produce agriculture in Nevada, some farmers have begun utilizing hoop houses to protect their produce. Hoop houses can be built to fit their owner's specifications and they can be as large as 10 m wide and 122 m long to less than 3 m wide and only 9 m long (NRCS, 2010). Despite these large variations in possible sizes, the general shape and construction of most hoop houses are similar. Hoop house generally have a rectangular footprint with two small end walls (where doors are located) that are connected by long tube-like bodies. The main bodies of the hoop houses are generally made from polyethylene strung over 'hoops', which are large metal or wooden rings. Depending on the price range and environment, the hoop house may also have other features, including roof vents, wall vents,

supplementary lighting, and moderate structural mobility. This design creates a relatively inexpensive greenhouse like environment. Greenhouses typically include sophisticated heating and cooling systems when built and therefore are much more effective at modulating the environment while costing significantly more (Badgery-Parker, 1999).

Hoop house use may be an exceptionally beneficial agriculture tool, but there are drawbacks or unknown qualities in their use. Similar to greenhouses, hoop houses are usually permanent structures and soil degradation can be a serious problem (Biernbaum, 2013). Furthermore, the polyethylene plastic commonly used to line hoop houses can block up to 50-60% of the ultraviolet spectrum (Kamweru et al., 2014). Lastly, reduced water loss and therefore water requirement are a supposed benefit of hoop house use, but this concept is poorly understood (Biernbaum, 2013).

Many farmers use hoop houses under the assumption that hoop houses benefit their farm by creating a more stable and controllable microclimate, without the high cost of a greenhouse (Walker et al., 2012). Unfortunately, few studies have investigated the effects of hoop house use in high desert agriculture. With the growing popularity of hoop house agriculture in northern Nevada, fully exploring hoop house benefits is essential.

Our studies investigated the effects of hoop house use in the high desert. Chapter 2 investigates effects of UV supplementation on antioxidant production in green-oak leaf lettuce. Chapter 3 investigates environmental changes caused by hoop houses, the effects of planting date on arugula and spinach grown over winter, and consumer preference of hoop house grown heirloom tomatoes, both between varieties and preference based upon planting date. The purpose of this research is to further our understanding of hoop house use.

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Subject Category: Vegetable Crops

Chapter 2: Ultraviolet supplementation as a technique for improving antioxidant content in green oak-leaf lettuce (*Lactuca sativa* (L.))

Additional index words. Vitamin E, Vitamin C, Total Polyphenolic, Spectroscopy, Greenhouse, Hoop house

Abstract. Ultraviolet (UV) radiation stimulates the formation of plant secondary products, such as pigments and phenolic compounds, some of which are beneficial to human nutrition. UV radiation is also known to be reduced in hoop house environments, potentially limiting secondary compound production. In hoop houses, supplemental UV radiation could be a useful and cost effective way to improve product nutritional quality and end-consumer health. In this study, we grew green oak-leaf lettuce within greenhouses and hoop houses and applied supplemental UV treatment at 64.4±0.9 J m^{-2} min^{-1} for varying durations. Leaf samples from green oak-leaf lettuce grown with supplemental UV treatment were then compared to samples from green oak-leaf lettuce grown without supplementation. Content of certain antioxidants (tocopherol, ascorbic acid, and total polyphenolics) and specific leaf area were tested to determine the effects of the supplemental UV treatment. In the greenhouse, no significant differences in plant response variables were found among any supplemental UV treatment duration. For the hoop houses, a significant increase in tocopherol content was found with 120 minutes of supplemental UV treatment, but no other plant response factors were significant. These conflicting results between greenhouse and hoop house experiments suggest that further study is needed in the hoop house environment to determine if other factors interact with supplemental UV treatment to affect tocopherol production. Given these results, we concluded that no recommendations can be made

to local farmers at this time to use supplemental UV radiation to increase green oak-leaf lettuce nutritional quality.

Introduction

Ultraviolet radiation is a highly energetic waveband, but only two portions of the UV spectrum reach the surface of the planet, UV-B (290-320 nm) and UV-A (320-400 nm). Current research has shown that exposure to UV-B is harmful to plant systems by increasing oxidative stress, which can damage proteins, including damage to photosystem 2 and rubisco (Teramura and Sullivan, 1994). The effects of this damage are far reaching, inducing physiological changes in leaves (Carvalho and Folta, 2014; Teramura and Sullivan, 1994), increase in phenolic compound production (Correia et al., 2012; Teramura and Sullivan, 1994; Vidovic et al., 2015), and changes in nutrient absorption, accumulation, and formation (Carvalho and Folta, 2014; Correia et al., 2012; Vidovic et al., 2015). Furthermore, reduction in UV-B exposure reduces phenolic compound production (Gotz et al., 2009), which implies that plants grown with reduced UV-B exposure may show similar results.

Oxidative stress is characterized by the creation of free radicals, which are atoms missing electrons in their outer shell that steal electrons from nearby atoms and molecules causing a chain of destabilization. All life systems have a natural response to oxidative stress by producing antioxidant chemicals (Stefanyk, 2011), such as tocopherol and ascorbic acid, which can donate electrons to reactive oxygen species without losing their own stability. Polyphenolic compounds are also known to have antioxidant properties through similar or yet unknown methods (Chandra et al., 2010). Humans cannot produce key antioxidants, and therefore, consumption of antioxidants is an important factor in a healthy diet. Adequate consumption of antioxidants has the potential to reduce the risk of chronic diseases by assisting the body's natural response to

oxidative stress (Chandra et al., 2010). Therefore, increasing the availability of antioxidant compounds in food, local or otherwise, has the potential to benefit human health.

In northern Nevada, hoop house agriculture is rapidly growing, as variable weather patterns, high and low temperature extremes, and high wind speeds are common in the area. Hoop houses are greenhouse like structures, composed generally of a metal or wood framework covered in plastic sheeting, which creates a more stable microenvironment for plant growth. In northern Nevada, a common hoop house is covered with slightly transparent white polyethylene plastic, a durable and cost efficient product that also happens to block 50% to 60% of the total UV spectrum (Kamweru et al., 2014). Although some hoop houses do have walls that can be raised or lowered to let in additional natural radiation and increase air flow, hoop house environments have permanently reduced UV exposure. We hypothesized that produce grown in hoop house environments suffer from reduced nutritional content as a direct result of limited UV exposure.

The purpose of this research is to determine if supplementation with UV radiation increases secondary compound production in green oak-leaf lettuce in hoop houses, and whether or not supplemental UV treatment can be implemented effectively in northern Nevada agriculture. This research studied changes in antioxidant content and specific leaf area as a result of UV exposure, and this research will ultimately assist in determining if UV supplementation of green oak-leaf lettuce is a beneficial method to improve human health.

Materials and methods

Location and growing conditions. The study was carried out in a glass greenhouse and polyethylene hoop houses that were located at the Valley Road Field Lab, Nevada Agricultural

Experiment Station, University of Nevada, Reno. The hoop houses used in this study are part of the Desert Farming Initiative farm, a fully operational hoop house farm that specializes in leafy salad mixes. The greenhouse used in this study is part of the Nevada Agricultural Experiment Station Greenhouse Complex. For all samples, green oak-leaf lettuce was chosen as a simple, well-studied test analog, which as a leafy vegetable would likely show changes as a result of supplemental UV treatment in the edible product.

Plants were grown in shielded enclosures that had clear, UV-shielding Mylar film along the sides but were open at the top (Fig. 2.1). UV radiation was applied by hanging reptile basking lights (Repti-Glo 10.0 Compact Fluorescent Desert Terrarium Lamp), which are designed to produce UV in similar ratios to the high desert environment. Each lamp produced an average of 64.4±0.9 J m^{-2} min^{-1} UV, as compared to our recorded maximums of 757±109 J m^{-2} min^{-1} during late November and 1.8±0.2 kJ m^{-2} min^{-1} during July under natural, clear sky conditions at the same locale. Greenhouse experiments consisted of five enclosures: one enclosure with no additional radiation, and the other four enclosures had 15, 30, 60, or 120 minutes of supplemental UV treatment twice a day. Enclosures were randomly distributed within the greenhouse, and each enclosure contained two pots. The pots were 0.3 m long X 0.3 m wide X 0.2 m deep, and each was densely seeded (40 seeds per row, with 4 rows at 50 mm apart per pot). Hoop house experiments were conducted using three enclosures and tested 120 minutes of supplemental UV treatment twice a day. One enclosure was used as a control with no additional radiation, one enclosure had a lamp shielded with Mylar (which shielded 99% of UV) to account for additional visible radiation from the lamp, and the last enclosure was unshielded to apply supplemental UV treatment. Within the hoop house, multiple varietals of lettuce were grown together, but only the “Green Saladbowl” variety, which is a green oak-leaf lettuce, was harvested. All enclosures were

randomly distributed within the hoop house and were orientated parallel to the rows. For all greenhouse and hoop house experiments, supplemental UV treatment was initiated approximately seven days after seeding when the first true leaves were approximately 5 mm long. For all greenhouse and hoop house experiments, daily supplemental UV treatment began at or just before sunrise (5:00 to 7:00 local time) and again before or just at sunset (17:00 to 19:00). These times were chosen to minimize potential effects of interrupting normal plant circadian cycles and to minimize UV exposure to workers at the facilities. In the greenhouse, pots were watered with soaker hoses connected to a small independent watering system and were watered regularly to maintain soils near field capacity. In the hoop house, plants were watered with a series of long drip tapes along the rows, and watering was maintained to near field capacity throughout the house.

Two trials were conducted in the greenhouse and one trial was conducted in the hoop house environment, and plant samples were collected at a total of six harvests. The greenhouse experiments ran from November 2016 – March 2017 and had two harvests from each of the two trials. The hoop house experiments ran from February 2017 – April 2017 and had two harvests.

Environmental monitoring. UV and air temperature were monitored in both greenhouse and hoop house experiments. UV data was collected at leaf canopy height using Apogee SU-100 sensors. In the greenhouse trials, UV sensors were placed at the center of both pots in each enclosure. In the hoop house experiment, UV sensors were placed underneath each lamp and within the control enclosure at the appropriate area to collect background UV. Air temperature data was collected using an Apogee ST-100 thermistor located underneath the UV lamp at plant leaf height and was shielded from direct solar radiation. A laboratory experiment was also conducted

testing only the amount of UV produced and potential temperature changes induced by each lamp in a stable environment. Campbell Scientific 200x series dataloggers were set to interrogate the sensors every minute, and data were averaged over an hour.

Sample collection. Sample collection occurred at regularly scheduled harvest times: 7 weeks and 11-14 weeks after planting for the greenhouse experiment, and 8 weeks and 10 weeks after planting in the hoop house experiments. Sample collection entailed harvesting all plant material above 25 mm, and plants regrew between the first and second harvest by producing new leaves from the center of the plant. From the total harvested plant material, 5 grams was taken and stored for chemical analysis, and ten leaves were chosen at random for use in specific leaf area (SLA) calculation. Remaining plant material was disposed of. All samples collected for chemical analysis were stored in a -80 °C freezer until chemical analysis was completed. SLA calculations were completed by using a die cutter with a diameter of 15 mm, taking cuts from each of the ten randomly selected leaves and drying those samples at 80 ºC until the weight was consistent (3 days).

Antioxidant analysis. Tocopherol content was analyzed using a modified method derived from Fabinek et al. (1968), which utilized bathophenanthroline spectrophotometry. One gram of leaf fragments was randomly sampled from stored plant material, to which 1 ml of absolute ethanol was added, and this mixture was then homogenized for 30 s without temperature control. The resulting homogenate was centrifuged for ten minutes at 3500 rpms refrigerated at 4 °C using a Sorvall RT6000B Refrigerated Centrifuge. Ten microliters of the supernatant was taken and mixed with 90 µl of absolute ethanol, which created a 1 ml solution with a 10 fold dilution of the sample. To each dilute solution, 1.2 ml of xylene was added, and each tube was centrifuged

again for 10 min while refrigerated at 4 °C. From the resulting supernatant, 100 µl was transferred into new tubes containing 0.4 ml of bathophenanthroline. To each tube, 0.4 ml ferric chloride [0.004 g/ml] and 0.4 ml of orthophosphoric acid [85%] were added to finish the coloration reaction. Standards were made using the same method with a known concentration between 0-30 µg/µl, using an alpha-tocopherol standard. When the coloration was completed [3 minutes], 200 µl of each tube, in triplicate, was moved into a Finstruments Microplate Reader and analyzed by a microplate reader at 350 nm. Tocopherol content was calculated from a standard curve when $R^2 > 0.95$.

Ascorbic acid analysis was conducted using a modified tissue method from Omaye et al. (1979). One gram of leaf fragments was randomly sampled from the stored plant material, 1 ml of 10% trichloroacetatic acid was added, and the combination was homogenized for 30 s without temperature control. The resulting homogenate was centrifuged for 10 min at 3500 rpms using a Sorvall RT6000B Refrigerated Centrifuge. After the samples were centrifuged, 100 µl of the supernatant was added to 900 µl of 10% trichloroacetatic acid. One milliliter of a mixture of 2,4-dinitrophenylhydrazine [0.03 g/ml], thiourea [0.004 g/ml], and cupric sulfate [0.0005 g/ml] in the presence of sulfuric acid was added to each tube. The tubes were covered and incubated at 37 ºC for 3 hours. After incubation, 1.2 ml of glacial sulfuric acid was added to each tube, whereupon the coloration reaction takes 30 min to finalize. Standards were made with L-ascorbic acid in 5% trichloroacetatic acid with a concentration between 0-80 µg/µl. From each tube, 200 µl, in triplicate, were transferred into a Finstruments Microplate Reader and analyzed at 520 nm. Ascorbic acid content was calculated from a standard curve when $R^2 > 0.95$.

Total polyphenolic content was analyzed using the Folin-Ciocalteu reagent. One gram of leaf fragments was randomly sampled, added to 1 ml of absolute ethanol, homogenized for 30 s without temperature control, and 9 ml of deionized H_2O was added to the resulting homogenate. The resulting mixture was centrifuged for 10 mins at 4 ºC using a Sorvall RT6000B Refrigerated Centrifuge. One ml of the supernatant was added to a tube with 1.58 ml of water. One hundred microliters of Folin-Ciocalteu reagent was added to each, mixed thoroughly, and 300 µl of a 25% sodium carbonate solution was added. The tubes were incubated at 40 ºC for 15 min. Standards were similarly made using Gallic acid with a range of 0-300 µg/µl. After the incubation, 200 µl, in triplicate, were transferred into a Finstruments Microplate Reader and analyzed at 690 nm. Total polyphenolic content was calculated from a standard curve when $R^2 > 0.95$.

Statistical analysis. Data were tested for normality using the Shapiro-Wilk Test and normality plots. Heteroscedasticity was tested with residual versus fitted plots. Data that were not normally distributed or had heteroscedasticity were transformed using the BoxCox method. Data from greenhouse experiments were first analyzed as 3-way ANOVAs in a randomized block design, with individual experiments as the blocking factor and three treatment factors of the spatial orientation of pots and UV radiation source, harvest date, and supplemental UV treatment duration. Because the spatial orientation factor and all its interaction terms were not significant in those ANOVAs, the statistical model was then simplified to a 2-way randomized block design. Thus, greenhouse experiments had two blocks (the two individual experiments) and 2 main factors (5 durations of supplemental UV treatment (0, 15, 30, 60, and 120 minutes)) and two harvest dates (two harvests per experiment). Data from hoop house experiment were analyzed as a split-plot ANOVA, with two harvest dates as the whole plot factor and three lamp configurations (no lamp, 120 minutes shielded lamp, and 120 minutes supplemental UV

treatment) as the split-plot factor. Any factor or interaction term that was statistically significant ($P \leq 0.05$) then had means compared using a Tukey correction.

Results

For the greenhouse experiments, data collected from the UV and air temperature sensors showed similar results to the laboratory experiment. UV exposure did double as the duration increased, applying 64.4±0.9 J m^{-2} min^{-1} UV. For example, 15 minutes supplemental UV treatment twice per day applied an average of 1.9 kJ m^{-2} day^{-1}, and 30 minutes of supplemental UV treatment applied an average of 3.9 kJ m^{-2} day^{-1}. For the greenhouse experiment, the glass blocked all natural UV radiation, and treatment was the only source of UV for the greenhouse experiments. For the hoop house experiment, the UV exposure increased similarly to the 120 minutes of supplemental UV treatment in the greenhouse experiments. UV treated plans in the hoop house received 15.5 kJ m^{-2} day^{-1} UV in addition to the average 42.1 kJ m^{-2} day^{-1} UV from natural radiation within each house.

Air temperature in the greenhouse varied between approximately 15 ºC to 25 ºC throughout the day. In the greenhouse, air temperature was increased by an average of 0.47 ºC during the 60 min and 120 min supplementation, as found in the laboratory experiment (Fig. 2.2), but a temperature difference wasn't noticeable for shorter durations. For the hoop house experiment, temperature throughout the experiment varied between an average nightly low 6 ºC to an average daily maximum of 24 ºC, but no discernable temperature difference occurred between control enclosures without UV lamps and enclosures with either mylar-shielded lamps or non-shielded lamps. For both experiments, the temperature increase, whether it was noticeable or not, was much smaller than the daily temperature cycles in each environment, approximately 10 ºC in the greenhouse and 27 ºC in the hoop house.

For the greenhouse experiments, spatial orientation between pots of plants and the UV radiation source was tested for its effect on the four response variables measured: SLA, tocopherol, ascorbic acid, and total polyphenolics. Because control plots did not have a UV lamp, this spatial orientation factor was only examined for data from UV treated green oak-leaf lettuce. The main effect of spatial orientation as well as its interactions with other factors were not significant for all of the response variables. For SLA, P-values were between 0.52-0.95; for tocopherol, P-values ranged between 0.83-0.99; for ascorbic acid, P-values ranged between 0.23-0.40; and for total polyphenolics, P-values ranged between 0.85-1.00. As a result, we simplified the statistical model and removed spatial orientation, and then added back the data from control plots for further statistical analyses.

For greenhouse experiments, neither of the main treatment effects nor their interaction term was significant for all response variables (Fig. 2.3). For SLA (Table 2.1A), no significant effects were found from supplemental UV treatment or harvest date. For tocopherol (Table 2.1B), no significant effects were found from supplemental UV treatment or harvest date. For ascorbic acid (Table 2.1C), no significant effects were found from supplemental UV treatment or harvest date. For total poly-phenolic (Table 2.1D), no significant effects were found from supplemental UV treatment or harvest date.

For the hoop house experiment, a significant effect of supplemental UV treatment was found for tocopherol, but no other effect from whole plot or split plot factors were significant for any other response variable (Fig. 2.4). For SLA, samples were pooled before measurements were made, and insufficient data was collected to analyze as a split-plot ANOVA; thus, these data were instead analyzed as a one-way ANOVA. No significant effects were found from supplemental

UV treatment for SLA (Table 2.2A). For tocopherol (Table 2.2B), significant effects were only found from supplemental UV treatment as compared to both the shielded lamp and the enclosure without a lamp present. For ascorbic acid (Table 2.2C), no significant effects were found from supplemental UV treatment or harvest date. For total polyphenolics (Table 2.2D), no significant effects were found from supplemental UV treatment or harvest date.

Discussion

Results of the greenhouse experiment show that this method of supplemental UV treatment has no significant effect on the production of tocopherols, ascorbic acid, or total polyphenolics in green oak-leaf lettuce. However, results of the hoop house experiment show a significant difference between the supplemental UV treatment and untreated green oak-leaf lettuce for tocopherol, but not for ascorbic acid or total polyphenolics. The results of our greenhouse study are consistent with previous studies, which also find no significant effect of supplemental UV treatment on tocopherol or ascorbic acid production for green oak-leaf lettuce (Li and Kubota, 2009; Samuolien˙e et al., 2013). The hoop house experiments showed a significant increase (roughly three times greater) in tocopherol production as a result the two hour twice a day treatment method used. Past studies on UV exposure on spinach have found a link between UV exposure and tocopherol content (DeLong and Steffen, 1997; Hectors et al., 2014; Yinan et al, 2015). It is likely that green oak-leaf lettuce responds similarly in vitro, but further study into the effect of supplemental UV would be necessary before a strong conclusion can be made. The total polyphenolic concentration for both experiments do not agree with the current literature that claims polyphenolic accumulation should occur with supplemental UV-B treatment (Avena-Bustillos et al., 2012; Garcia-Macias et al., 2007; Lee et al., 2013; Leon-Chan et al., 2017; Romani et al., 2002; Xu et al., 2013). UV-A supplementation is shown to reduce polyphenolic

production, and the UV supplementation in this study applied both UV-B and UV-A (Tsormpatsidis et al., 2008). The presence of UV-A supplementation and the small quantity of supplemental UV in both experiments may have resulted in an undetectable change in polyphenolic content.

Supplemental UV treatment did not significantly affect SLA, regardless of treatment duration. This result does not agree with the consensus in current literature (Carvalho and Folta, 2014; Lee et al., 2013; Wargent et al., 2009), where UV exposure is shown to reduce SLA and decrease overall growth. The inconsistency found here is most likely due to the low level UV-A and UV-B exposure used in this experiment, as many of these experiments treated their plants with 3-4 kW m^{-2} UV, which is over 20 times greater than the 130 W m^{-2} applied during our maximum supplemental UV treatment.

We can conclude supplemental UV treatment in a hoop house environment on green oak-leaf lettuce requires further study. The significant increase in tocopherol content coupled with no detectable effect on polyphenolic content conflicts with previous literature and may be a new interaction for further investigation. Nonetheless, supplemental UV treatment as described in this study is not conclusively effective enough to recommend as a growing technique for local farmers using hoop houses.

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Table 2.1. Results from ANOVAs of data collected from two greenhouse experiments that tested the effects of different durations of supplemental UV exposure on green oak-leaf lettuce.

	Factor	Num df[y]	Den df[x]	F	p
A. Specific leaf area					
	Harvest	1	1	1.66	0.52
	UV Treatment	4	1	0.46	0.62
	Harvest*UV Treatment[z]	4	1	0.39	0.82
B. Tocopherol					
	Harvest	1	1	0.10	0.96
	UV Treatment	4	1	0.52	0.60
	Harvest*UV Treatment[z]	4	1	0.01	1.00
C. Ascorbic Acid					
	Harvest	1	1	12.59	0.18
	UV Treatment	4	1	1.50	0.54
	Harvest*UV Treatment[z]	4	1	0.47	0.78
D. Total Polyphenolics					
	Harvest	1	1	0.23	0.90
	UV Treatment	4	1	0.05	0.86
	Harvest*UV Treatment[z]	4	1	0.12	0.96

[z]Interaction effect of Harvest and UV treatment duration.

[y]Degrees of freedom for the effect term.

[x]Degrees of freedom for the error term.

Table 2.2. Results from ANOVAs of data collected from one hoop house experiment that tested the effects of different durations of supplemental UV exposure on green oak-leaf lettuce.

	Factor	Num df[y]	Den df[x]	F	p
A. Specific leaf area					
	UV Treatment	2	5	0.41	0.70
B. Tocopherol					
	Harvest	1	2	5.82	0.14
	UV Treatment	2	2	71.13	0.01*
	Harvest*UV Treatment[z]	2	2	3.92	0.20
C. Ascorbic acid					
	Harvest	1	2	4.96	0.27
	UV Treatment	2	2	0.19	0.85
	Harvest*UV Treatment[z]	2	2	0.07	0.93
D. Total Polyphenolics					
	Harvest	1	2	2.10	0.38
	UV Treatment	2	2	0.88	0.60
	Harvest*UV Treatment[z]	2	2	0.05	0.95

[z]Interaction effect of Harvest and UV treatment duration.

[y]Degrees of freedom for the effect term.

[x]Degrees of freedom for the error term.

*Significant to a ($P \geq 0.05$)

Fig. 2.1. Pictured here is an enclosure used in the study for Chapter 2, specifically for the hoop house experiment. Enclosures were open top and 0.5 m tall, 0.9 m long, and 0.6 m wide. For each enclosure, the lamp was located at the north end to minimize shading of plants. Sides of the enclosures are lined with Type D Mylar that blocks 99% of UV radiation so that plants outside the enclosures are not exposed to additional UV radiation. In the hoop house experiment, green oak-leaf lettuce was grown amongst other greens.

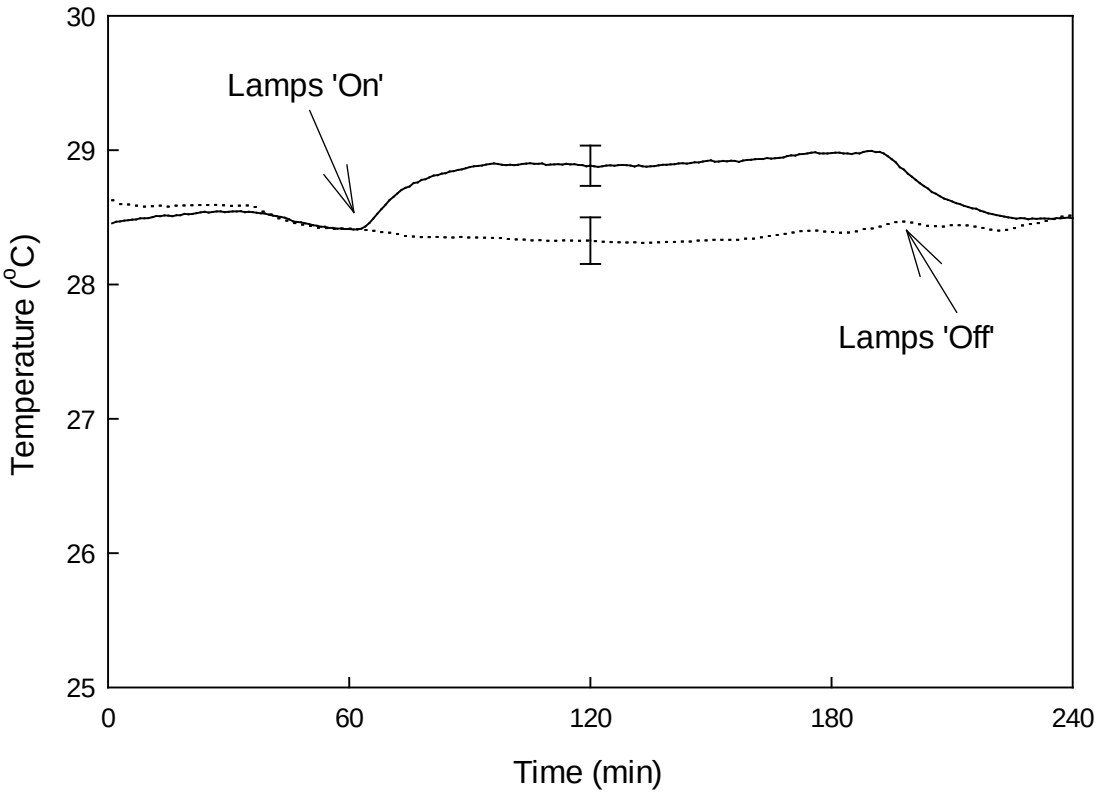

Fig. 2.2. Results of a laboratory test completed on four lamps, all used during the greenhouse experiments. Four lamps were placed at the same height as all other experiments, 0.5 m, above UV and temperature sensors and programmed to run for two hours each with a two hour period of darkness between them. An additional set of sensors was placed in another location within the lab to record a control value. Dataloggers were set to record data every minute, and data was averaged over the four consecutive trials. The dotted line represents the control temperature and the black line represents the temperature underneath the lamps. Arrows on the graph indicate when the lamps were turned on or off during the experiment. The error bar on each line represents the average standard error for the values collected during the experiment when lamps were on.

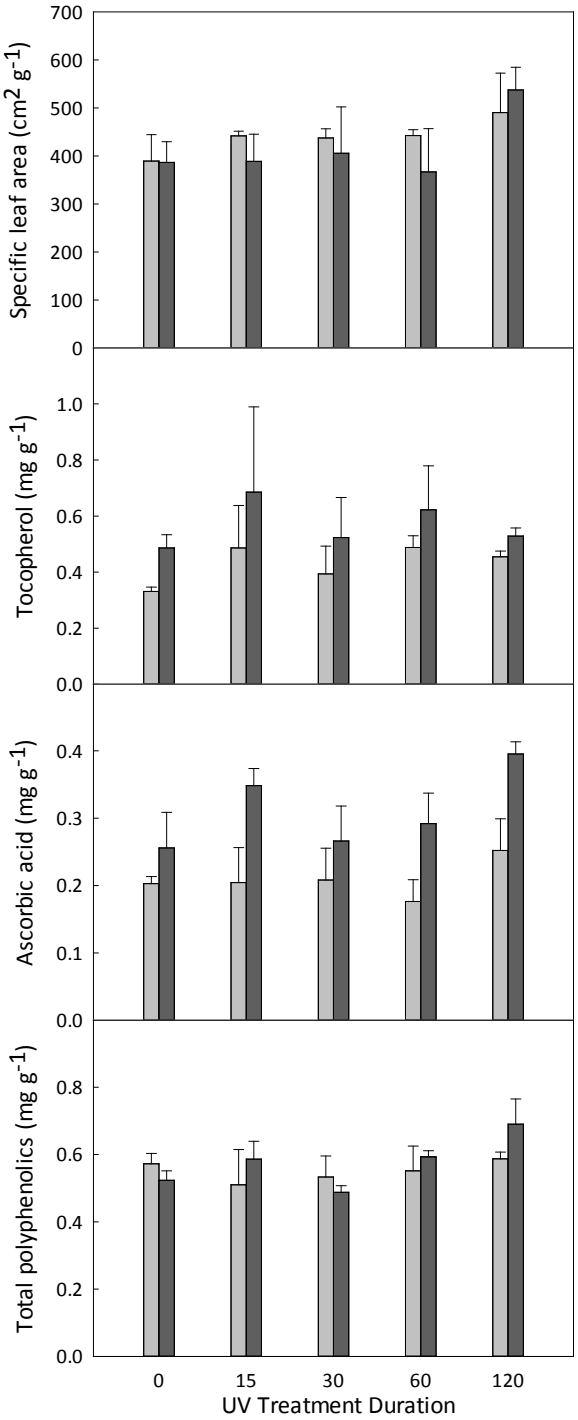

Fig. 2.3: Results from two greenhouse experiments that tested the effects of different durations of supplemental UV exposure on specific leaf area (top panel), leaf tocopherol content (second panel from the top), leaf ascorbic acid content (third panel from the top), and leaf total polyphenolic content (bottom panel). Light gray bars are means from the first harvest of both trials, and dark gray bars are means from the second harvest of both trials. Means and standard errors are shown for the control group with no UV treatment and plants exposed to 15, 30 60 and 120 minutes supplemental UV exposure twice a day. Means and standard errors are averaged over both experiments. No significant differences were found as a result of supplemental UV treatment for all four leaf response variables.

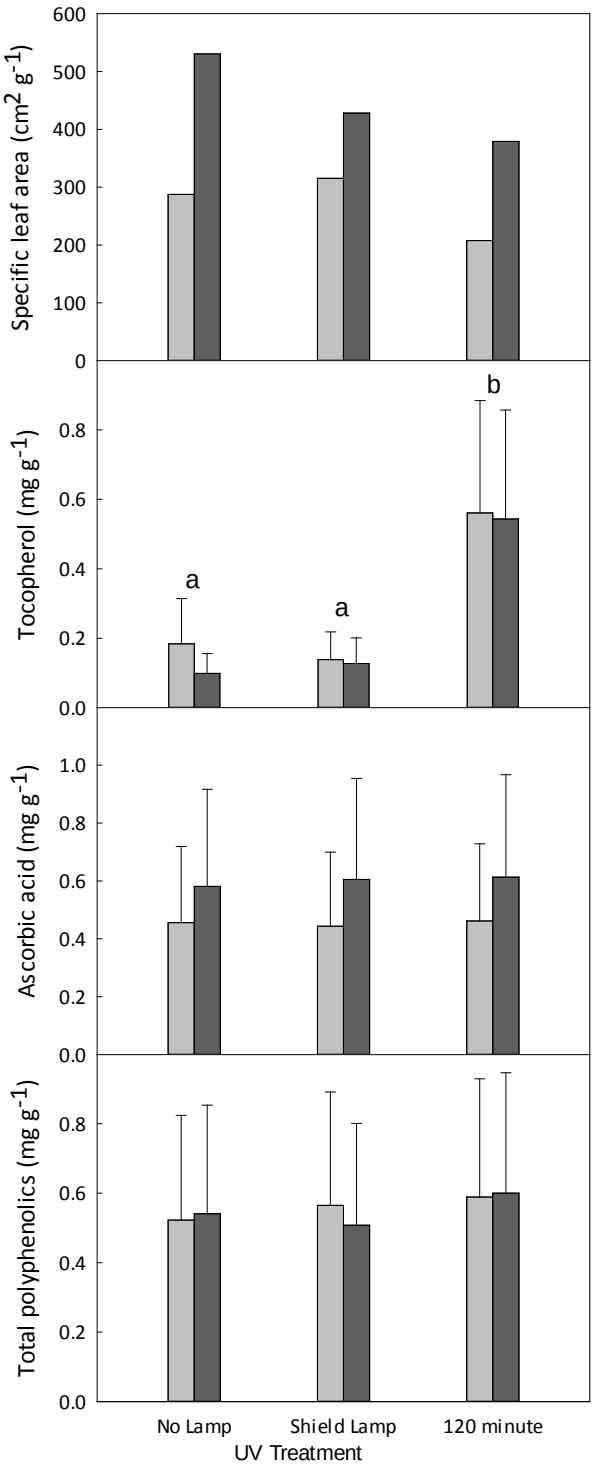

Fig. 2.4: Results from the hoop house experiment that tested the effects of different durations of supplemental UV exposure on specific leaf area (top panel), leaf tocopherol content (second panel from the top), leaf ascorbic acid content (third panel from the top), and leaf total polyphenolic content (bottom panel). Light gray bars are means from the first harvest, and dark gray bars are means from the second harvest. Means and standard errors are shown for the control enclosure with no lamp, the 120 minute shielded (no UV) lamp twice a day, and the 120 minute supplemental UV treatment twice a day. Significant differences (a b) were found in the concentrations of leaf tocopherol content as a result of supplemental UV treatment as compared to both the shielded lamp and no lamp samples. Means with a common letter are not significantly different ($P \leq 0.05$).

Subject Category: Vegetable Crops

Chapter 3: The effects of hoop house agriculture on environmental responses and seasonal extension: Four studies investigating the benefits of hoop houses

Additional index words. Eruca sativa, *Spinacia oleracea*, Vitamin E, Vitamin C, Total Polyphenolic, Spectroscopy, Hoop house

Abstract. Produce farming in northern Nevada is commonly done within hoop houses. Unfortunately, few studies have tested the benefits or drawbacks of hoop house use. Four studies were completed in hoop houses and nearby uncovered plots to document or test certain aspects of hoop house agriculture. The first study documented environmental data from both hoop houses and uncovered plots and concluded hoop houses created a microclimate with greater air temperature and soil water content. The second study tested the effect of planting date on the antioxidant content of two winter greens, *Eruca sativa* (arugula) and *Spinacia oleracea* (spinach). The second study concluded that planting date does not have a significant effect on antioxidant content, but tocopherol content of spinach and ascorbic acid content of both arugula and spinach increased from December to March regardless of when the plants were originally planted in the fall. The last two studies tested consumer preference for three varieties of heirloom *Lycopersicon lycopersicum* (tomato) called Black Cherry, New Yorker, and Pink Berkeley Tie Dye (PBTD). The third study tested consumer preference among these three varieties, and we concluded that Black Cherry and New Yorker tomatoes were preferred equally over PBTD. The fourth tested consumer preference between a sample harvested from an early planting date and a sample harvested from a later planting date of the same variety, and we concluded that the early

planting date of New Yorker and PBTD tomatoes produce more preferred fruit and that Black Cherry tomatoes have no major preference based on planting date.

Introduction

Farming produce in the high desert is a difficult task. Temperatures in northern Nevada fluctuate significantly from night to day. For example in the Reno area, daily temperature in the middle of summer changes between 32 ºC during the day and 24 ºC during the night, and temperature in the middle of winter changes between 12 ºC during the day and 0 ºC during the night. With an average of 0.18 m of rainfall each year, humidity and water is naturally scarce. Furthermore, the growing season is only 85-90 days (Nevada Department of Agriculture, 1976). This short growing season limits local farmers' abilities to grow profitable quantities of produce and places increased strain when competing with nearby farmers in the California Central Valley.

As a result, some local farmers in northern Nevada grow entire farms underneath hoop houses. A hoop house is a greenhouse like structure, composed of a metal or wood framework covered in durable plastic sheeting. Hoop house companies and hoop house farmers claim hoop houses create a stable microclimate for produce production by increasing the overall temperature, reducing water loss to evaporation, and increasing the growing season by months (Walker et al., 2012). Unfortunately, hoop houses can have expensive startup costs and inherently limit growing space, and the microclimate it produces may affect produce in unknown ways. Furthermore, few studies have investigated the benefits of hoop house agriculture in the high desert.

In order to determine the validity of claims made about hoop houses, four studies were completed. First, environmental data was collected from both hoop houses and nearby uncovered plots to document their microclimate differences. Second, antioxidant content of leafy greens grown in hoop houses were analyzed to investigate differences based on planting date. Third, a consumer preference study was completed on three varieties of hoop house grown tomatoes to

investigate if consumers preferred certain varieties over the others. Finally, a second consumer preference study was completed on the same three tomato varieties to investigate if consumers preferred tomatoes from plants planted in hoop houses early in the growing season versus those from plants planted later in the growing season. The purpose of this research is to document benefits or drawbacks associated with the use of hoop houses in high desert agriculture.

Materials and Methods

Location and growing conditions. These studies were carried out within polyethylene hoop houses and within adjacent uncovered plots located at the Nevada Agricultural Experiment Station, Main Station Field Lab, University of Nevada, Reno. All hoop houses and uncovered plots were constructed and maintained by student researchers and were used exclusively for student studies. Four separate polyethylene hoop houses and two uncovered plots, which were located between houses, were used in these studies. All hoop houses and plots ran parallel to each other and faced south, with rows aligned on the east/west axis to maximize warming during the winter months (Walker et al., 2012). Each house and plot had four planting rows that ran lengthwise. All produce grown in these studies were chosen by the project horticulturalist for suitability to high desert climate or consumer interest.

All produce were watered by planting row, using a pair of one inch drip tapes that ran parallel to the row, and watering was maintained to near field capacity. When the irrigation system failed, hand watering was used judiciously to maintain field capacity. Temperature control for hoop houses was maintained by opening or closing end-wall doors and roll up sides that allowed air flow. All produce were planted and grown using methods chosen by the project horticulturalist.

First study: Comparison of microclimate between hoop houses and natural environments. To determine differences between hoop house and uncovered environments in the high desert, environmental data was collected in all plots. Air temperature data was collected using a Campbell HMP60-L Thermometer located near the western wall of each hoop house and in the center of each uncovered plot. Soil temperature was collected using Type-K Thermocouples and was measured in the center of each planting row at both 50 mm and 0.1 m beneath the surface. Soil water content in the top 0.3 m of soil was collected using Campbell CS655 Soil Content Reflectometers placed near the center of the row. Ultraviolet radiation (UV) and Photosynthetically Active Radiation (PAR) were measured using Apogee SU-100 and SQ-110 sensors, respectively, that were located slightly west of center. A combination of Campbell Scientific dataloggers [200X, 10X, and 21X series] were set to interrogate sensors every minute, and data were averaged over an hour. All data collected from these sensors were stored on a combination Campbell Scientific 200X, CR10, and 21X series dataloggers.

Data collected were analyzed by graphing averaged uncovered plot values minus average hoop house values and applying a Loess smoothing curve. Lines were placed on each graph to indicate when the three most recent studies had taken place, and a zero line was added to show where uncovered plot values were greater than hoop house values. Monthly precipitation records from NOAA's Reno NV National Weather Service Forecast Office for the same time period that we measured environmental data were also graphed.

Second study: Comparison of antioxidant content of Eruca sativa (L.)(arugula) and Spinacea oleracea (L.) (spinach) grown in hoop houses with different planting dates. To test the effects of planting date on winter produce in the high desert, several varieties of both leaf and root produce

were planted successively within hoop houses and uncovered plots. The first planting was on October 2, 2015, and a subsequent planting occurred for most produce every three weeks for a total of three successive plantings (planting one, planting two, and planting three in order). Each row within a house or plot was planted as a replicate, and produce grown for this study were insulated using 10 mm drop cloth hung at 0.3 m above the row when air temperature was predicted to drop below 5 ºC.

Two varieties were sampled for this experiment, arugula and spinach, both of which survived the winter inside the hoop house. Arugula was harvested twice (December 16, 2015 and March 3, 2016), and spinach was harvested three times (December 16, 2015, March 3, 2016, and April 4, 2016). Each harvest removed approximately one third of total leaf foliage. From total harvested plant material, 15-30 grams was taken and stored for chemical analysis. All samples collected for chemical analysis were stored in a -80°C freezer until chemical analysis was completed.

Tocopherol content was analyzed using a modified method derived from Fabinek et al. (1968), which utilized bathophenanthroline spectrophotometry. One gram of leaf fragments was randomly sampled from stored plant material, to which 1 ml of absolute ethanol was added, and this mixture was then homogenized for 30 s without temperature control. The resulting homogenate was centrifuged for ten minutes at 3500 rpms refrigerated at 4 °C using a Sorvall RT6000B Refrigerated Centrifuge. Ten microliters of the supernatant was taken and mixed with 90 µl of absolute ethanol, which created a 1 ml solution with a 10 fold dilution of the sample. To each dilute solution, 1.2 ml of xylene was added, and each tube was centrifuged again for 10 min while refrigerated at 4 °C. From the resulting supernatant, 100 µl was transferred into new tubes containing 0.4 ml of bathophenanthroline. To each tube, 0.4 ml ferric chloride [0.004 g/ml] and

0.4 ml of orthophosphoric acid [85%] were added to finish the coloration reaction. Standards were made using the same method with a known concentration between 0-30 μg/μl, using an alpha-tocopherol standard. When the coloration was completed [3 minutes], 200 μl of each tube, in triplicate, was moved into a Finstruments Microplate Reader and analyzed by a microplate reader at 350 nm. Tocopherol content was calculated from a standard curve when $R^2 > 0.95$.

Ascorbic acid analysis was conducted using a modified tissue method from Omaye et al. (1979). One gram of leaf fragments was randomly sampled from the stored plant material, 1 ml of 10% trichloroacetatic acid was added, and the combination was homogenized for 30 s without temperature control. The resulting homogenate was centrifuged for 10 min at 3500 rpms using a Sorvall RT6000B Refrigerated Centrifuge. After the samples were centrifuged, 100 μl of the supernatant was added to 900 μl of 10% trichloroacetatic acid. One milliliter of a mixture of 2,4-dinitrophenylhydrazine [0.03 g/ml], thiourea [0.004 g/ml], and cupric sulfate [0.0005 g/ml] in the presence of sulfuric acid was added to each tube. The tubes were covered and incubated at 37 ºC for 3 hours. After incubation, 1.2 ml of glacial sulfuric acid was added to each tube, whereupon the coloration reaction takes 30 min to finalize. Standards were made with L-ascorbic acid in 5% trichloroacetatic acid with a concentration between 0-80 μg/μl. From each tube, 200 μl, in triplicate, were transferred into a Finstruments Microplate Reader and analyzed at 520 nm. Ascorbic acid content was calculated from a standard curve when $R^2 > 0.95$.

Total polyphenolic content was analyzed using the Folin-Ciocalteu reagent. One gram of leaf fragments was randomly sampled, added to 1 ml of absolute ethanol, homogenized for 30 s without temperature control, and 9 ml of deionized H_2O was added to the resulting homogenate. The resulting mixture was centrifuged for 10 mins at 4 ºC using a Sorvall RT6000B Refrigerated

Centrifuge. One ml of the supernatant was added to a tube with 1.58 ml of water. One hundred microliters of Folin-Ciocalteu reagent was added to each, mixed thoroughly, and 300 µl of a 25% sodium carbonate solution was added. The tubes were incubated at 40 ºC for 15 min. Standards were similarly made using Gallic acid with a range of 0-300 µg/µl. After the incubation, 200 µl, in triplicate, were transferred into a Finstruments Microplate Reader and analyzed at 690 nm. Total polyphenolic content was calculated from a standard curve when $R^2 > 0.95$.

Data were tested for normality using the Shapiro-Wilk Test and normality plots. Heteroscedasticity was tested with residual versus fitted plots. Data that were not normally distributed or had heteroscedasticity were transformed using the BoxCox method. Data were analyzed using a two-way ANOVA comparing response variables to planting date and harvest date. Any factor that was statistically significant ($P \leq 0.05$) had means compared using a Tukey correction.

Third and fourth studies: Consumer preference testing among hoop house grown Lycopersicon lycopersicum (L.) H. Karst (tomato). Consumer preference testing was completed on three heirloom tomatoes called Black Cherry, New Yorker, and Pink Berkeley Tie Dye (PBTD). Two adjacent rows from each house or uncovered plot were planted with three of each variety of tomato. Each house or uncovered plot had one half planted on March 11, 2016 (planting one) and the other half planted on June 11, 2016 (planting two), creating two separate sets based on planting date. In uncovered plots, no tomato plants survived from the March 11th planting due to extreme weather conditions and no edible tomatoes were harvested from uncovered plots from the June 11th planting. As a result, all samples included in these studies were grown inside hoop

houses. Watering during these studies varied before July 27 2016, because hand watering was used instead of drip tape.

An eleven-question preference survey was developed to determine which of two samples were more preferred. The eleven categories tested were: color, smell, juiciness, acidity, skin toughness, flesh texture, tomato flavor, tomato quality, likelihood to purchase, and likelihood not to purchase. One preference survey, which was our third study of hoop house benefits, determined consumer preference among the three varieties, and the other preference survey, which was our fourth study of hoop house benefits determined consumer preference between two samples of the same variety but one sample from each planting date. Subjects were given two blind samples per survey, asked to observe and taste each sample, and to choose which sample they preferred for each question. For the third study, three surveys were used, one sample-coded survey per sample combination: Black Cherry versus PBTD, PBTD versus New Yorker, and Black Cherry versus New Yorker. For the fourth study, one survey was used per sample, coding samples for the first planting versus the second planting. In addition to sample preference questions, three questions were asked about subject demographics: subject gender, subject age range, and whether or not the subject works in food service. These studies were reviewed under IRB Project 862007-1 and granted exemption status on February 2, 2016.

Data were collected from volunteers at local farmers markets and University of Nevada, Reno events. These venues were the University of Nevada, Reno “Ag Field Day”, University of Nevada, Reno students in the nutrition program, and consumers at the following farmers markets: North Marketplace Farmers Market (August 8, 2016), Summit Sierra Farmers Market (August 23, 2016 and September 27, 2016), and the Sand’s Regency Farmers Market (August

25, 2016). Each location was notified of the study beforehand, and letters of approval for operation were obtained for each non-University event.

Data were analyzed using a test proportion for each question. A test proportion of 0.5 was chosen to represent no significant preference between samples. Data that was significantly different ($p \leq 0.05$) from the test proportion were considered to indicate significant preference differences between samples. Due to the nature of preference studies and proportion testing, subjects that answered both or did not answer a question were not counted as a part of sample size of that question, resulting in varying sample sizes per question.

Results

First study: Comparison of microclimate between hoop houses and natural environments. Air temperature data that were averaged over a week typically were warmer in hoop house environments than uncovered plots (Fig. 3.1). Weekly average temperatures in hoop houses were warmer by up to 7 ºC, and weekly maximum temperatures were warmer by up to 11 ºC. On average, hoop house weekly minimum temperatures were warmer by at least 0.5 ºC. Seasonally, average and maximum air temperature differences were greater during summer and smaller during winter. During late 2016, however, hoop house weekly average and maximum air temperatures became cooler than the outside environment by up to 6 ºC. Fortunately, hoop houses minimum air temperature did not change appreciably either seasonally or during late 2016, resulting in warmer minimum air temperature in hoop house environments throughout the study duration.

The difference between hoop house environments and uncovered plots for soil temperature that was averaged over a day showed large and frequent fluctuations during our study (Fig. 3.2). Both magnitude and temporal trend of this difference in soil temperature are similar at 50 mm and 0.1 m. Before April 2016, hoop house soils were typically warmer. Between April 2016 and September 2016, three large fluctuations in soil temperature occurred of up to 14 ºC. After September 2016, soil temperature were cooler in hoop houses. Unlike air temperature, which was almost always warmer inside hoop houses, soil temperature did not appear to follow a seasonal temperature variation at either 50 mm or 0.1 m.

Hoop houses generally had higher soil moisture levels based on soil water content data that were averaged over a day (Fig. 3.3). This trend was greatest during the second, third and fourth studies conducted within the hoop house, where hoop houses had about 14% more soil water content. In periods when uncovered plots had greater soil water content, the maximum difference was approximately 4%. No clear seasonal trend appeared, but soil water content appeared to fluctuate between higher values in hoop houses then to uncovered plots every few months.

For radiation data, uncovered plots always had greater UV and PPFD readings. For UV, uncovered plots showed a greater total daily exposure of approximately 0.8 MJ m^{-2} d^{-1}, except between June and August where the total exposure difference increases to an average of 3.9 MJ m^{-2} d^{-1} (Fig. 3.4). For PPFD, uncovered plots showed a greater total daily exposure of around 15 mol m^{-2} d^{-1}, except between June and August where the total exposure increases to an average 70 mol m^{-2} d^{-1} (Fig 3.5). Radiation data varied seasonally, with the largest differences during the summer when days are longer and sun intensity is greatly increased.

Second study: Comparison of antioxidant content of Eruca sativa (L.)(arugula) and Spinacea oleracea (L.) (spinach) grown in hoop houses with different planting dates. For arugula, no significant differences were found in tocopherol content as a result of planting date or harvest date (Table 3.1A, Fig. 3.6). For ascorbic acid (Table 3.1B), significant differences were found from harvest date, but no other factors were significant. Tocopherol content was found to significantly increase for the first planting from the December 16, 2015 harvest to the March 3, 2016 harvest. For total polyphenolics (Table 3.1C), no significant differences were found from planting date or harvest date.

For spinach, significant differences were found in tocopherol content as a result of harvest date, but no other factors were significant (Table 3.2A, Fig. 3.6). Tocopherol content was found to significantly increase for the first planting from the December 16, 2015 harvest to the March 3, 2016 harvest, but significantly decrease between the March 3, 2016 harvest and the April 4, 2016 harvest, with no significant difference between the December 16, 2015 harvest and the April 4, 2016 harvest. For ascorbic acid (Table 3.2B), significant differences were found from harvest date, but no other factors were significant. Ascorbic acid content was found to increase from the December 16, 2015 harvest to both the March 3, 2016 harvest and the April 4, 2016 harvest. For total polyphenolics (Table 3.2C), no significant differences were found from planting date.

Third and fourth study: Consumer preference testing among hoop house grown Lycopersicon lycopersicum (L.) H. Karst (tomato). For the third study, a total of 75 subjects were surveyed (Fig. 3.7). Subjects from this study were primarily female, primarily between the ages of 30 and 69, and primarily did not work in food service. For the fourth study, a total of 118 subjects were

surveyed (Fig. 3.7). Subjects from this study were more evenly gender distributed, with an age range between 18 and 69, and primarily did not work in food service.

For surveys testing Black Cherry against PBTD, consumer's preferred Black Cherry tomatoes in seven different categories (smell, juiciness, skin toughness, better texture, tomato flavor, tomato quality, and likelihood to purchase) and preferred PBTD in one category (tougher skin) (Table 3.3A). For surveys testing PBTD against New Yorker, consumers preferred New Yorker tomatoes in six different categories (smell, juiciness, better texture, tomato flavor, tomato quality, and likelihood to purchase) and PBTD in one category (likelihood not to purchase) (Table 3.3B). For surveys comparing Black Cherry against New Yorker, no significant preferences were found (Table 3.3C).

For surveys testing Black Cherry planting one against planting two, consumers preferred planting one in one category (juiciness) and preferred planting two in one category (worse acidity) (Table 3.4A). For surveys testing New Yorker planting one against planting two, consumer preferred planting one in three categories (tomato flavor, tomato quality, and likelihood to purchase) and planting two in three categories (tougher skin, worse texture, and likelihood not to purchase) (Table 3.4B). For surveys testing PBTD planting one against planting two, consumers preferred planting one in two categories (tomato flavor and likelihood to purchase) and planting two in two categories (worse texture and likelihood not to purchase) (Table 3.4A).

Discussion

First study: Comparison of microclimate between hoop houses and natural environments.

Results from our air temperature measurements are consistent with claims made about hoop house agriculture (Upson, 2014; Walker et al., 2012; Zaworski, 2018). Typically, air temperature was warmer in hoop houses as opposed to uncovered plots. This trend appeared to deviate in July – September 2016, when air temperature outside hoop houses was greater by a maximum of about 6 ºC. We hypothesized that this deviation was caused by evaporation and transpiration cooling. During this time, large quantities of tomatoes were producing inside hoop houses for the third and fourth studies, and a failure in the watering system required manual watering during that period. Hand watering was applied to the tomato canopy, and water likely collected in small pools left on leaves and other surfaces. It has been shown that through evaporation cooling and a natural pressure gradient pulling the air from within the hoop house, water vapor could escape the hoop houses through the open sides, reducing the total air temperature within each house (Bartok, 2005). Furthermore, similar to trees, it is possible that the tomato plant's natural transpiration aided in reducing the hoop houses temperature (NIFA, 2012). Low relative humidity and air pressure can increase transpiration rates in plants, both factors common in the northern Nevadan climate (Leopold, 1960). It is likely the abundant water and high transpiration rates during this period resulted in cooling the hoop house environment. To further support this hypothesis, relative air temperature begins to rapidly approach 0 near the end of the third and fourth studies, when most plants reached senescence as the summer growing season ended. During this time both watering and transpiration rates would have decreased, reducing the cooling effect within the hoop house environment.

The results of soil temperature data were inconclusive. Data before April 2016 appeared to show hoop houses having warmer soil temperature, but data collected between April 2016 and September 2016 showed large temperature fluctuations. We hypothesized that the soil temperature fluctuations were a result of air temperature. During this time, maximum and average air temperature fluctuates in a similar fashion to the soil temperature. Soil moisture, which was higher during this period of time due to planting and inconsistent watering, also is a major factor in determining local soil temperature (TAFE Connect, n. d.). It is likely air temperature fluctuations, coupled with a moist soil, resulted in the soil temperature variations. Furthermore, after September 2016, soil temperature appeared higher in the uncovered plots.

Relative soil water content fluctuated often. On average, however, relative soil moisture was higher in hoop houses. Unfortunately, no trend appears within the data to explain the periods when relative soil moisture was greater in the uncovered plots, and monthly precipitation does not appear to have an effect. In such a period, between April and July 2016, we hypothesized relative soil water content fluctuation may have been caused by inconsistent hand watering. Whereas the automatic watering system was meant to maintain field capacity, hand watering is not nearly as efficient or consistent, suffering from problems with runoff and evaporation (Liu et al., 2012; Westarp et al., 2004; Woltering et al., 2011). Furthermore, hand watering was applied liberally during this time to attempt to maintain plant growth in the uncovered plots.

Uncovered plots received more UV and PPFD exposure than hoop houses. UV and PPFD both showed similar trends to seasonal trends in total incident radiation intensity, which indicated a portion of the radiation spectrum was being absorbed before reaching the interior of hoop houses. PPFD was likely impacted heavily by the plastic covering. The type of plastic used for

the hoop houses, both in composition and manufacturing, along with the accumulation of dust and other debris can reduce the transparency of plastic and limit PPFD penetration significantly (Biernbaum, 2013). The reduction in UV was likely due to the polyethylene material used in the hoop house construction which is known to absorb radiation in the UV (Kamweru et al., 2014).

We conclude from these results that hoop houses produce microclimates with higher air temperatures and potentially higher soil water content when watering remains constant. We also confirm that hoop houses receive less PPFD and UV at all times.

Second study: Comparison of antioxidant content of Eruca sativa (L.)(arugula) and Spinacea oleracea (L.) (spinach) grown in hoop houses with different planting dates. Significant differences in antioxidant content were inconsistent. For both arugula and spinach, planting date did not induce any significant change, but antioxidant content changed significantly through time as plants grew during the growing season. Ascorbic acid content for planting one of arugula increased by 0.3 mg g^{-1} between the first harvest in December and second harvest in March. Tocopherol content for planting one of spinach increased during the second harvest as compared to the other two harvest by approximately 0.5 mg g^{-1}, and ascorbic acid content increased by 0.3 mg g^{-1} from the first harvest to both the second and third harvests. Although both produce shared an increase in antioxidant production from harvest one to harvest two for planting one, only the increase in ascorbic acid is consistent. It is known that plant maturity does not affect spinach ascorbic acid levels, but growing conditions and soil quality do (Tressler et al., 1936). Radiation intensity and temperature are major factors affecting plant ascorbic acid content, with lower radiation and colder temperature creating less ascorbic acid production (Lee and Kader, 2000). Taking those factors into account, it is much more likely that the plants harvested during the first

harvest would have significantly lower ascorbic acid levels than future harvests, given that those plant had grown in low radiation with cold temperature (between October 2, 2015 and December 16, 2015). Therefore, we conclude growing conditions, more than planting date or harvest date, were more likely the main factor in determining antioxidant production. Farmers using hoop houses should take radiation and temperature into account to avoid low antioxidant content.

Third and fourth studies: Consumer preference testing among hoop house grown Lycopersicon lycopersicum (L.) H. Karst (tomato). For the third study, consumer preference was conclusive. PBTD, when compared to both Black Cherry and New Yorker, was found to be less preferred in smell, juiciness, tomato flavor, and tomato quality. However, neither Black Cherry nor New Yorker were preferred over the other. Consumer preference favors Black Cherry and New Yorker equally over PBTD. Previous research indicates that sweetness and red tomato color are two of the most important factors in tomato taste preference (Johansson et al., 1999). Furthermore, cherry tomatoes often are highly preferred among tomato varieties (Causse et al., 2003; Serrano-Megias and Lopez-Nicolas, 2006). It is likely PBTD was less preferred than the other tomatoes due to its striped green and red coloration and its savory flavor, whereas the New Yorker is bright tomato red and Black Cherries are a sweet cherry tomato variety. Based on consumer preference, we recommend Black Cherry and New Yorker instead of PBTD to local hoop house farmers.

For the fourth study, consumer preference was not consistent for all varieties. For Black Cherry tomatoes, consumer preference was not very conclusive, with planting one slightly preferred over planting two. For New Yorker tomatoes, consumer preference was very conclusive, with planting one preferred over planting two. For PBTD tomatoes, consumer preference was fairly

conclusive, with planting one more preferred than planting two. We hypothesized that preference between planting one and planting two were a result of water stress induced by inconsistent watering during the period study. Drought stress is known to increase the color and soluble sugars of tomatoes, both primary factors in tomato preference (Johansson et al., 1999; Pulupol, et al., 1996). Furthermore, larger plants tend to suffer more from water stress, as the competition between fruit production and maintaining plant biomass greatly reduce their water use efficiency (Blum and Sullivan, 1997). The tomatoes planted earlier in the season would have a greater plant biomass as compared to the later planting, resulting in tomatoes grown under greater water stress, which would in turn, make sweeter better colored tomatoes. The results of the fourth study suggest that planting Black Cherry, New Yorker, and PBTD earlier in the growing season does not affect the quality of the tomato grown, but instead inducing water stress during flowering and fruit production may improve tomato quality.

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Table 3.1. Results from ANOVAs of data collected from a hoop house that tested effects of planting date on arugula. Each response listed refers to the leaf component.

	Factor	Num df[z]	Den df[y]	F	p
A. Tocopherol					
	Harvest	1	2	10.91	0.08
	Planting	1	2	0.32	0.63
B. Ascorbic Acid					
	Harvest	1	2	21.50	0.04*
	Planting	1	2	0.01	0.92
C. Total Polyphenolics					
	Harvest	1	2	5.05	0.15
	Planting	1	2	0.07	0.82

[z]Degrees of freedom for the effect term.

[y]Degrees of freedom for the error term.

*Significant to a ($P \geq 0.05$)

Table 3.2. Results from ANOVAs of data collected from a hoop house experiment that tested effects of planting date on spinach. Each response listed refers to the leaf component.

	Factor	Num df[y]	Den df[x]	F	p
A. Tocopherol					
	Harvest	2	2	96.04	0.01*
	Planting	2	2	14.90	0.06
	Harvest*Planting[z]	1	2	5.34	0.15
B. Ascorbic Acid					
	Harvest	2	2	63.96	0.02*
	Planting	2	2	1.43	0.41
	Harvest*Planting[z]	1	2	0.21	0.69
C. Total Polyphenolics					
	Harvest	2	2	3.99	0.20
	Planting	2	2	1.34	0.43
	Harvest*Planting[z]	1	2	5.12	0.15

[z]Interaction effect of Harvest date and Planting Date.

[y]Degrees of freedom for the effect term.

[x]Degrees of freedom for the error term.

*Significant to a ($P \geq 0.05$)

Table 3.3. Results from proportion tests of data collected from a taste-testing experiment that tested the differences in consumer preference among three varieties of heirloom tomatoes, Black Cherry (BC), Pink Berkeley Tie Dye (PBTD), and New Yorker (NY). Varieties were tested two at a time among 11 identical categories, and each category was tested individually for significant differences.

Question	Preference	n^z	p	N^y	Preference	n^z	p	N^y	Preference	n^z	p	N^y
	A. BC vs PBTD			27	B. PBTD vs NY			24	C. BC vs NY			23
Color	None	24	0.68		None	24	0.41		None	20	0.37	
Smell	BC	25	0.04*		NY	22	0.04*		None	21	0.51	
Juiciness	BC	24	0.01*		NY	22	0.00*		None	21	0.27	
Acidity	None	13	0.76		None	19	0.17		None	19	0.25	
Tougher skin	PBTD	19	0.02*		None	19	0.13		None	16	0.62	
Better texture	BC	25	0.00*		NY	24	0.02*		None	19	0.49	
Worse Texture	None	11	0.76		None	8	0.76		None	8	0.47	
Tomato flavor	BC	25	0.00*		NY	22	0.04*		None	21	0.83	
Tomato quality	BC	24	0.00*		NY	22	0.02*		None	19	0.82	
Likelihood to purchase	BC	23	0.00*		NY	20	0.00*		None	16	1.00	
Likelihood not to purchase	None	12	0.21		PBTD	12	0.01*		None	8	0.48	

[z]Sample size per question.

[y]Sample size per survey.

*Significant to a ($P \leq 0.05$)

Table 3.4. Results from proportion tests of data collected from a taste-testing experiment that tested the differences in consumer preference between an earlier and later planting of three varieties of heirloom tomatoes, Black Cherry (BC), Pink Berkeley Tie Dye (PBTD) and New Yorker (NY). Varieties were tested individually among 11 identical categories, and each category was tested individually for significant differences.

Question	Preference	n[z]	p	N[y]	Preference	n[z]	p	N[y]	Preference	n[z]	p	N[y]
	A. BC			46	B. NY			38	C. PBTD			34
Color	None	42	0.35		None	34	0.17		None	27	0.85	
Smell	None	34	0.73		None	37	0.62		None	28	0.27	
Juiciness	Planting 1	39	0.02*		None	35	0.87		None	27	0.18	
Acidity	Planting 2	35	0.03*		None	32	0.48		None	24	0.41	
Tougher skin	None	38	0.33		Planting 2	32	0.00*		None	27	0.85	
Better texture	None	40	0.11		None	37	0.14		None	28	0.25	
Worse texture	None	23	0.53		Planting 2	23	0.03*		Planting 2	15	0.01*	
Tomato flavor	None	44	0.76		Planting 1	37	0.04*		Planting 1	30	0.03*	
Tomato quality	None	44	0.76		Planting 1	38	0.03*		None	31	0.11	
Likelihood to purchase	None	40	0.53		Planting 1	34	0.01*		Planting 1	28	0.03*	
Likelihood not to purchase	None	26	0.69		Planting 2	27	0.01*		Planting 2	16	0.02*	

[z]Sample size per question.

[y]Sample size per survey.

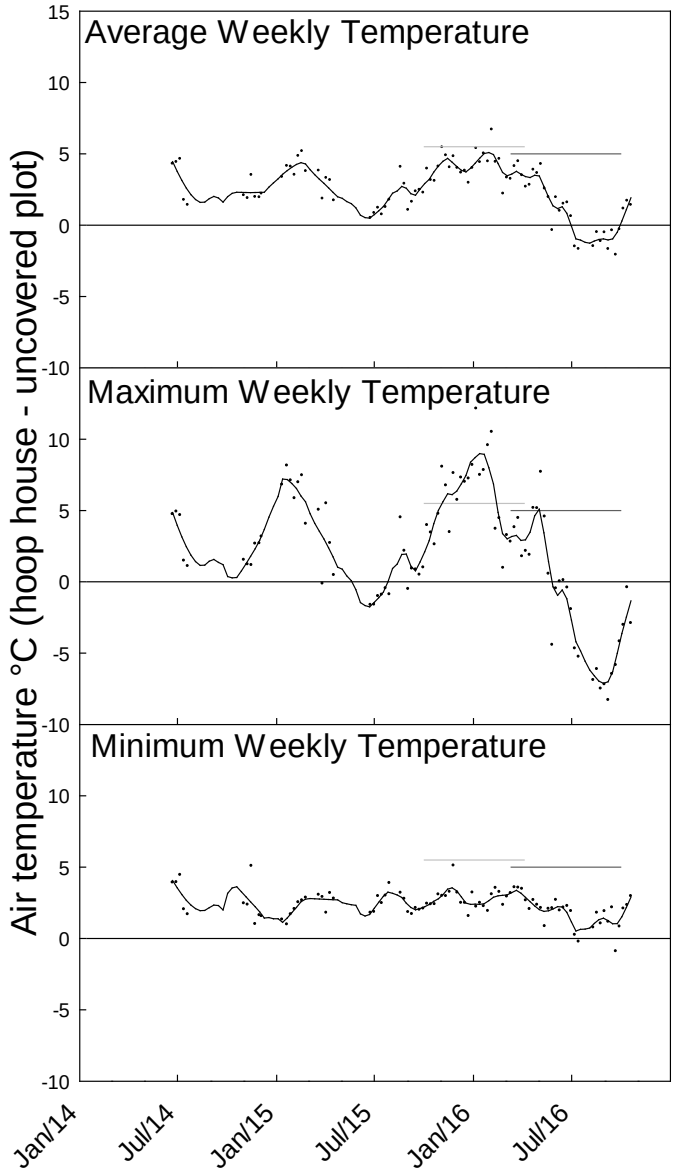

Fig. 3.1: The differences between weekly air temperatures of hoop house records minus uncovered plot records fitted with a Loess curve. The top panel refers to the average weekly temperature, the middle panel refers to the average maximum weekly temperature, and the bottom panel refers to the average minimum weekly temperature. Temperature data was collected hourly in each location and overaged over a week for each graph. On each panel, the time frame for the second study (light gray line) and the time frame for the third study (dark gray line) are shown for reference.

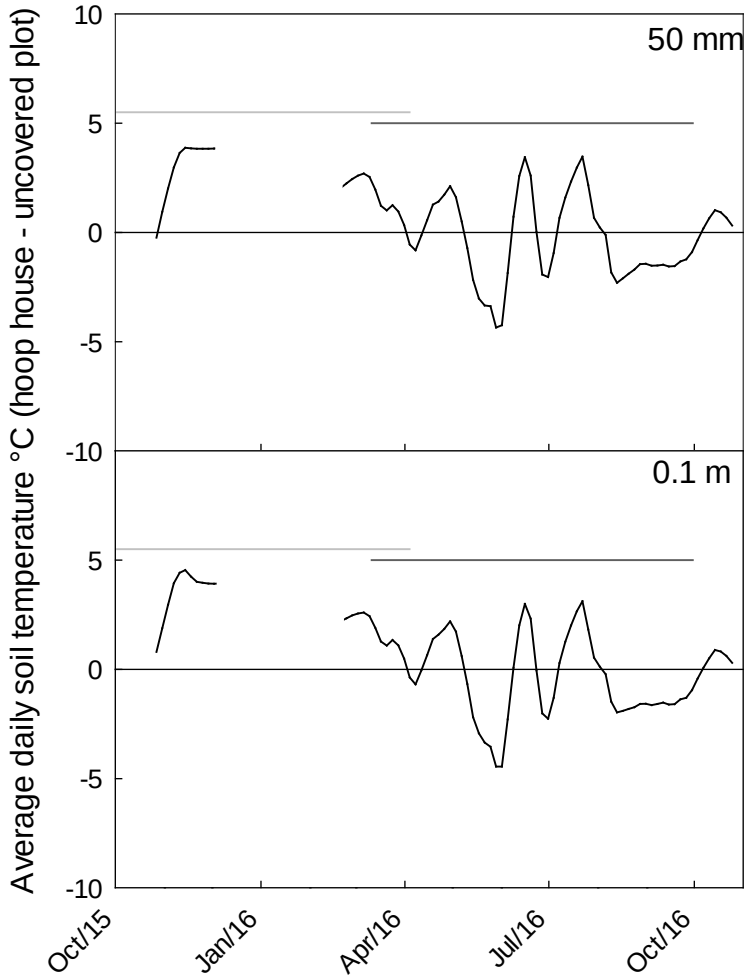

Fig. 3.2: The differences between average daily soil temperature data collected at 55 mm (top panel) and 0.1 m (bottom panel) of hoop house records minus uncovered plot records fitted with a Loess curve. Soil temperature data was collected in each of four rows per location. All values collected were first averaged over all four rows in each location, then averaged among four hoop houses and two uncovered plots. On each panel, the time frame for the second study (light gray line) and the time frame for the third study (dark gray line) are shown for reference.

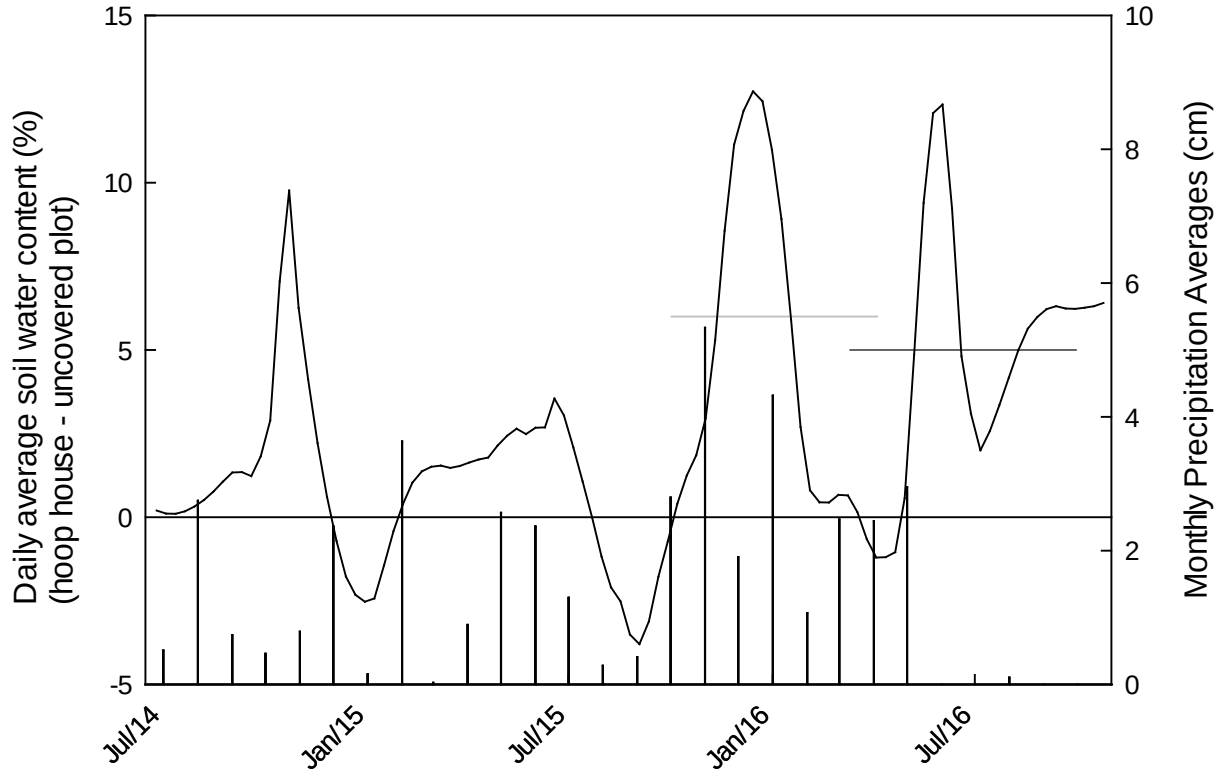

Fig. 3.3: The difference between daily average soil water content of hoop house records minus uncovered plot records fitted with a Loess curve, overlaid with the monthly average precipitation data collected from the NOAA Reno, Nevada weather station. All values collected were first averaged over all four rows in each location, then averaged among four hoop houses and two uncovered plots. The time frame for the second study (light gray line) and the time frame for the third study (dark gray line) are shown for reference.

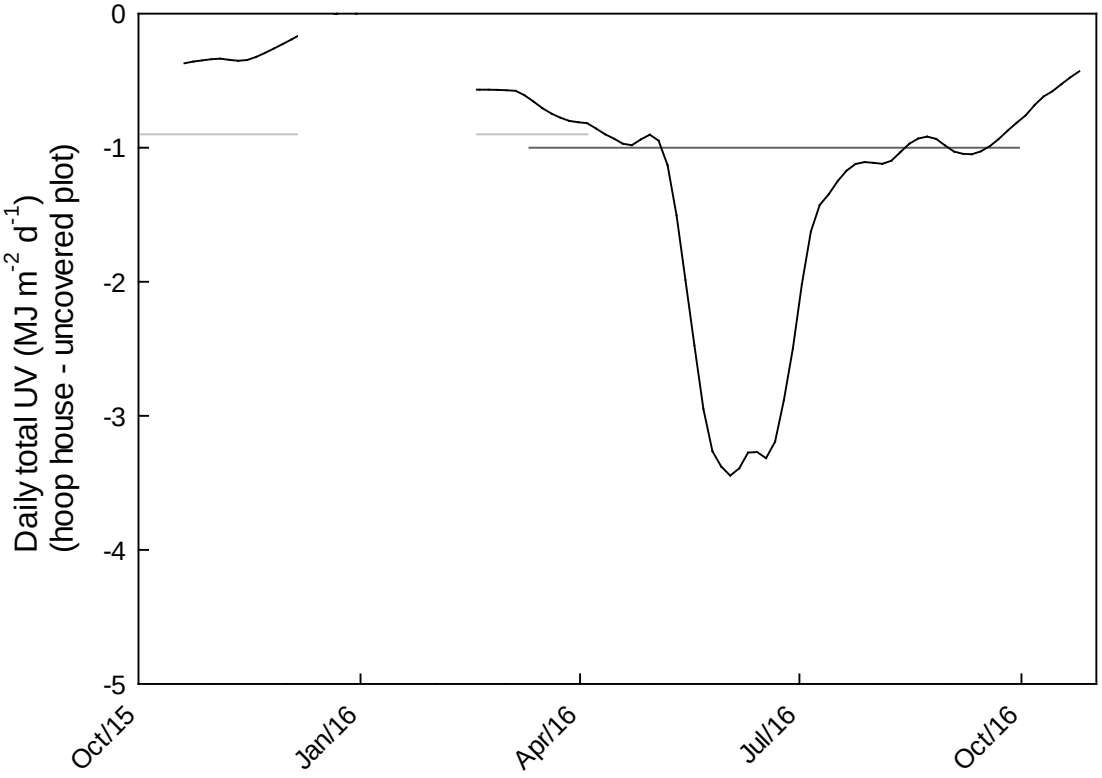

Fig. 3.4: The difference between daily maximum UV exposures of hoop house records minus uncovered plot records fitted with a Loess curve. UV data was collected per location and averaged among four hoop houses and two uncovered plots. The time frame for the second study (light gray line) and the time frame for the third study (dark gray line) are shown for reference.

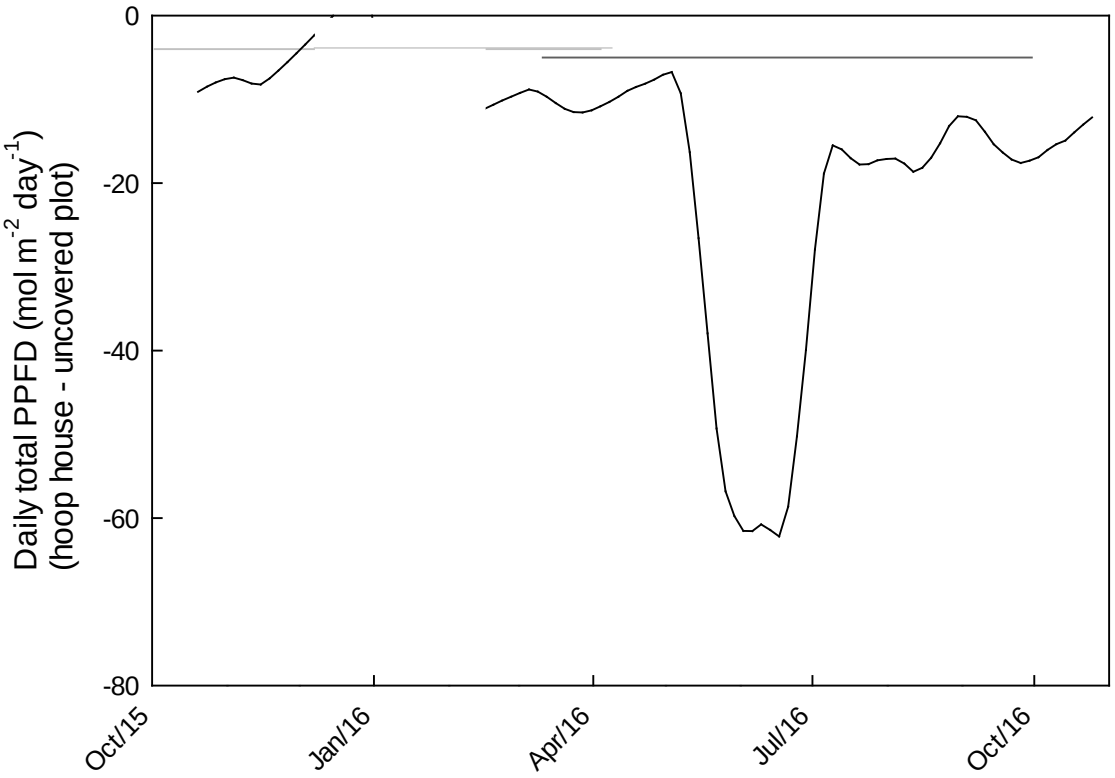

Fig. 3.5: The difference between daily total photosynthetic photon flux density (PPFD) of hoop house records minus uncovered plot records fitted with a Loess curve. PPFD data was collected per location and averaged among four hoop houses and two uncovered plots. The time frame for the second study (light gray line) and the time frame for the third study (dark gray line) are shown for reference.

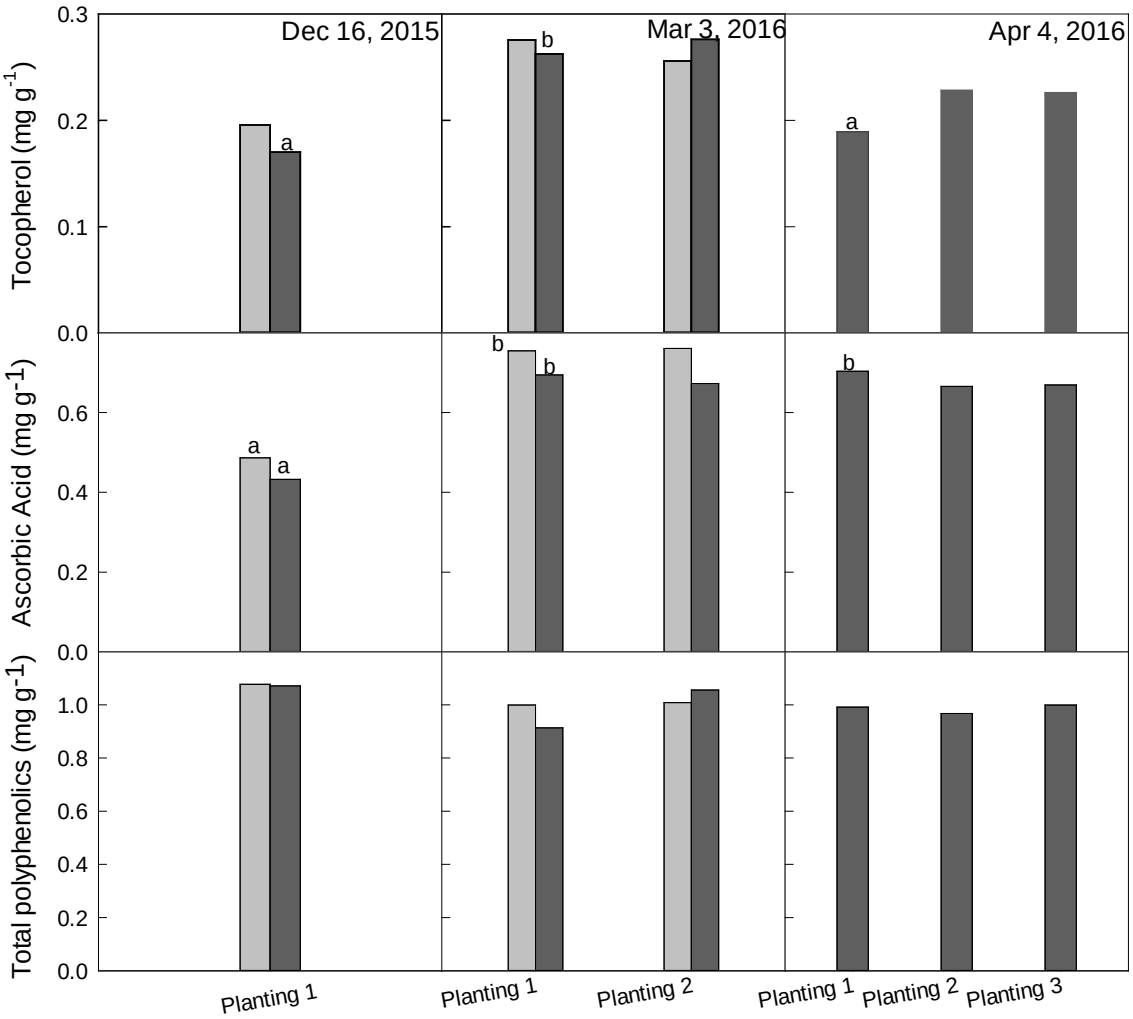

Fig. 3.6: Results from the second study which tested the effects of planting date on leaf tocopherol content (top row), leaf ascorbic acid content (middle row), and leaf total polyphenolic content (bottom row). Each column represents the sampling date, December 16, 2015, March 3 2016, and April 4, 2016. Light gray bars are means from the arugula, and dark gray bars are means from the spinach. Means are shown for each value based on planting. Means are averaged over all harvests. Significant differences (a b) were found in the concentrations of leaf antioxidant content as a result of harvest date. Means with a common letter are not significantly different ($P \leq 0.05$)

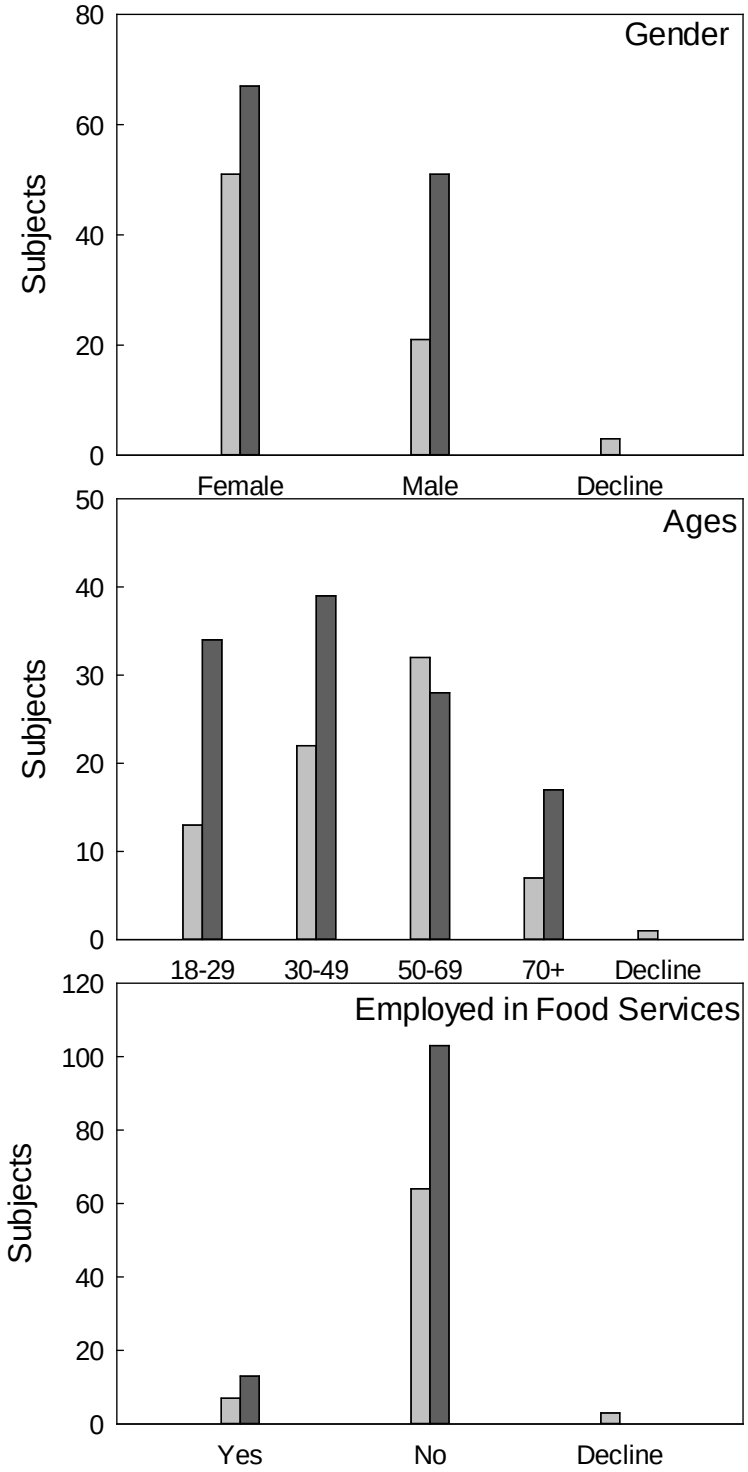

Fig. 3.7: Demographical data recorded for the third and fourth studies which tested consumer preference for three varieties of heirloom tomatoes. The light gray bars represent the third study and the dark gray bars represent the fourth study.

Chapter 4: Conclusion

From the research completed in Chapter 2, supplemental UV treatment in a hoop house environment to green oak-leaf lettuce has potential but requires further study. Although tocopherol content increased significantly in the hoop house environment, not finding an effect in the greenhouse environment is troubling. Furthermore, not finding an effect on total polyphenolics despite a known president for increased polyphenolic production indicates an unknown factor may be involved (Avena-Bustillos et al., 2012; Garcia-Macias et al., 2007; Lee et al., 2013; Leon-Chan et al., 2017; Romani et al., 2002; Xu et al, 2013)). Small sample size for the hoop house trials limits the statistical strength of the results, increasing the possibility of a Type 1 error. Supplemental UV has shown to increase tocopherol content in spinach, and it is very possible a similar effect can been seen in green oak-leaf lettuce (DeLong and Steffen, 1997; Hectors et al., 2014; Yinan et al, 2015). UV supplementation, according to the methods described in Chapter 2, may be an effective way to improve produce antioxidant quality in the hoop house environment.

Our results for the first study in Chapter 3 indicate hoop houses create a microclimate different from the uncovered environment. Hoop houses create a warmer environment during the daytime while minimally affecting nighttime temperature. Air temperature in hoop houses also appears to the main factor in determining soil temperature. Hoop houses also appear to increase soil water content, but this effect may be confounded by inconsistent watering and relative soil quality (Liu et al., 2012; Westarp et al., 2004; Woltering et al., 2011). UV and PPFD is greatly reduced in the hoop house environment, although this effect is dependent on building material and upkeep (Biernbaum, 2013; Kamweru et al., 2014).

For the second study, we concluded that antioxidant appears to be more directly a factor of growing condition rather than planting. Previous work showed that ascorbic acid content was positively influenced by radiation exposure and warmer temperatures (Lee et al., 2000). This effect likely explains the statistical difference found between the December and April harvest where radiation intensity and temperature would vary greatly during growth. We recommend farmers intending to grow winter green harvest before the darkest parts of winter or wait until spring to maintain peak antioxidant content.

From the third and fourth studies, our results for the third study indicate Black Cherry tomatoes and New Yorker tomatoes are preferred over PBTD. Past work has shown that color and sweetness are the most impactful variables in human preference for tomatoes, which keeps in line with our findings (Johansson et al., 1999). Black cherry tomatoes are sweet and the red tomato color of the New Yorker overshadowed the green and red striped savory flavor of the PBTD. The results from our fourth study suggest water stress in conjunction with plant size heavily impact consumer preference for New Yorker and PBTD. Previous studies have found water stress to be a key factor in determining tomato quality, with larger plants suffering more heavily from water stress than smaller plants (Blum and Sullivan, 1997; Pulupol, et al, 1996). Therefore, given the effect planting early has on New Yorker and PBTD we suggest planting early in the growing seasons, in the case of our research March. By planting these early it appears to improve consumer preference significantly. Black Cherry tomatoes, on the other hand, do not follow this trend as strongly, and appear to be equally preferred planted earlier and later in the year.

Our research has brought to light new features of hoop house agriculture. The connection we found between supplemental UV and tocopherol content indicate possible new techniques for

more nutritious produce production in hoop house agriculture. The environmental changes recorded here show a strong connection between air temperature, soil temperature, and soil moisture in the hoop house microclimate, highlighting the benefits of careful control and drawbacks of inconsistent care. We found that planting date of winter greens did not impact antioxidant content and, although harvest date was found significant, environmental factors were likely the more significant factors. Farmers with the means to modulate light and temperature in their hoop houses can harvest winter greens through the dark cold winter without sacrificing antioxidant content. Otherwise we suggest harvesting either before or after the harshest winter months, when nutritional content will be decreased. We recommend planting New Yorker and Black Cherry tomatoes over PBTD planting New Yorker and PBTD tomatoes earlier in the growing season. Results from our third and fourth study indicate these practices increase consumer preference. Northern Nevadan hoop house agriculture still need more study, but the research completed here will help elucidate the mysteries of hoop house use.

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