2024 NCERA-101 Station Report from Georgia

State rep: Dr. Rhuanito Ferrarezi (CEA Crop Physiology and Production Lab, http://ferrarezilab.uga.edu)

Other faculty members: Dr. Andrew Ogden, Dr. Erich Schoeller, Dr. Ruchika Kashyap and Dr. Zhihang Song (both new, hired within the report period)

1. New Facilities and Equipment. In terms of facilities, we acquired a renovated 25' x 42' research greenhouse. Concerning equipment, we acquired a benchtop VNIR (visible + near infrared) hyperspectral imaging system from Resonon Inc., two industrial-level 3D printers (Bambu Lab X1E and Formlabs Form 4) for rapid prototyping, a Campbell Scientific CR1000Xe datalogger and AM16/32B channel relay multiplexer, 8 Apogee Instruments SQ-610-SS EPAR sensors, 12 Onset Hobo MX2301A Temperature/RH Sensors, and a Hanna Instruments Portable pH/EC Meter.

2. Unique Plant Responses.

From the Ferrarezi Lab:

1. **Lowering Target Daily Light Integrals for Cost Efficiency:** Lettuce exhibited adaptability to fluctuating light conditions by maintaining biomass production despite reduced light input after excessive exposure. This suggests potential for energy savings in CEA without sacrificing yield.

2. **Optimized Light Use Efficiency in Hydroponic Lettuce**: Lettuce demonstrated differential photosynthetic efficiency under varying light intensities, indicating the importance of strategic light allocation for maximizing growth while minimizing energy costs.

3. **Imaging System Validation for Petunia Analysis**: Petunia plants exhibited predictable morphological and pigmentation changes in response to varying fertilizer rates and pH levels, confirming the reliability of an in-house imaging system for plant trait analysis.

4. **Effects of Light Intensity on Lettuce Growth**: Lettuce showed significant physiological plasticity in response to different light intensities, with higher intensities promoting biomass accumulation but also increasing photoprotective responses.

5. **Low-Cost Multispectral Imaging for Canopy Analysis**: Advanced imaging enabled precise quantification of lettuce canopy size and pigmentation, providing insights into how plants dynamically adjust their architecture under different light conditions.

6. **Nitrogen Uptake and Biomass Productivity**: Bibb lettuce displayed a nonlinear nitrogen uptake pattern, with microbial activity playing a key role in nutrient availability and plant growth under DWC hydroponic conditions.

7. **Light and Temperature Impact on Wheat and Rice Growth**: Both crops exhibited differential growth responses, with rice being more sensitive to temperature fluctuations, while wheat showed enhanced biomass accumulation under higher light intensities.

8. **Potassium Concentration and Adaptive Lighting Effects on Lettuce**: Variations in potassium availability influenced lettuce morphology, leading to changes in leaf expansion and pigmentation. An adaptive lighting system optimized growth efficiency under these conditions.

9. **GA3 Effects on Salt-Stressed Lettuce Seedlings**: Automated imaging revealed that exogenous gibberellin (GA3) application improved seedling vigor and mitigated the negative effects of salt stress on lettuce germination and early development.

10. **Seed Aging and Lettuce Germination Performance**: Imaging techniques quantified the decline in seed germination rate and vigor due to aging, helping to identify optimal storage conditions for maintaining seed quality.

11. **Low-Cost Imaging for Germination Analysis Across Lettuce Cultivars**: Differences in germination speed and early seedling growth among cultivars were effectively captured, providing a cost-effective tool for seed quality assessment.

12. **Beneficial Microbes Alleviate Salinity Stress in Hydroponic Greens**: Microbial inoculation improved lettuce and pak choi resilience to salinity stress, enhancing root development and overall plant health under hydroponic conditions.

13. **Anthocyanin Concentrations and Light Effects on Lettuce**: Lettuce plants modulated anthocyanin accumulation in response to light variations, suggesting a photoprotective role and potential for manipulating pigmentation through controlled lighting.

14. **Heterografting to promote cold tolerance in cucumber.** Growth chamber study revealed transcriptomic changes in cucumber plants grafted to cold tolerant rootstocks exposed to chilling stress. Grafting strategy is being explored as a tool for reducing heating inputs in off-season greenhouse cucumber production.

15. **Cultivar and substrate affect yields of greenhouse grown parthenocarpic zucchini.** High rates of aborted fruit reported among cultivars purported to be parthenocarpic. Breeding efforts are needed to increase the rate of parthenocarpic fruit set. Subsequent studies to focus on fertilization and irrigation rates for greenhouse parthenocarpic zucchini production.

3. Accomplishments:

3.A. Short-term Outcomes:

From the Ferrarezi Lab:

1. **Lowering the Target Daily Light Integrals for Cost Reduction (Mayorga et al., 2024, Frontiers in Plant Sciences)**

    a. Identified potential cost savings in lettuce production by adjusting light integrals based on prior lighting conditions.

   b. Provided immediate recommendations for energy-efficient lighting strategies in controlled environments.

2. **Optimizing Light Use Efficiency in Hydroponic Lettuce (Palsha et al., 2024, Agronomy)**

   a. Determined optimal light intensity levels for maximizing photosynthetic efficiency in hydroponic lettuce.

   b. Suggested improved energy allocation strategies for controlled environment agriculture (CEA).

3. **Validating an In-House Imaging System for Petunia Analysis (Wacker et al., 2024, Sensors)**

   a. Demonstrated the reliability of an in-house imaging system for plant analysis across fertilizer and pH variations.

   b. Provided validation for cost-effective phenotyping solutions in CEA.

4. **Lettuce Growth Under Varying Light Intensities (Mayorga et al., 2024, Horticulturae)**

   a. Quantified physiological and morphological lettuce responses to different light intensities.

   b. Offered data-driven recommendations for optimizing indoor lettuce production.

5. **Automated Low-Cost Multispectral Imaging System (Wacker et al., 2024, Sensors)**

   a. Developed a cost-effective imaging system for canopy size and pigmentation analysis.

   b. Provided an accessible tool for plant monitoring in research and commercial settings.

6. **Modeling Nitrogen Uptake in Bibb Lettuce (Sharkey et al., 2024, Agriculture)**

   a. Established a predictive model for nitrogen uptake and biomass productivity in hydroponic lettuce.

   b. Contributed to improved nutrient management strategies in vertical farming.

7. **Light and Temperature Effects on Wheat and Rice Growth (Thies et al., 2024, Horticulturae)**

   a. Examined interactive effects of light and temperature on wheat and rice under controlled conditions.

   b. Provided preliminary insights for optimizing cereal crop growth in CEA.

8. **Hydroponic Lettuce Response to Potassium and Adaptive Lighting (Palsha et al., 2024, HortScience)**
    a. Identified changes in lettuce morphology and physiology under varying potassium levels and adaptive lighting.
    b. Suggested targeted nutrient and lighting adjustments to enhance growth.
9. **Automated Imaging for GA3 Effects on Salt-Stressed Lettuce Seeds (Iradukunda et al., 2024, Sensors)**
    a. Used imaging to quantify the impact of gibberellin (GA3) on salt-stressed lettuce seedlings.
    b. Demonstrated a novel, non-destructive method for evaluating seedling stress responses.
10. **Imaging for Seed Aging and Vigor Analysis (Iradukunda et al., 2024, Sensors)**
    a. Showed how imaging techniques can assess seed aging and vigor across lettuce cultivars.
    b. Provided a rapid, cost-effective approach for seed quality evaluation.
11. **Low-Cost Imaging for Lettuce Germination and Vigor (Iradukunda et al., 2024, Sensors)**
    a. Developed an imaging-based tool to assess germination rates and seedling vigor.
    b. Enabled efficient screening of seed quality for commercial and research applications.
12. **Beneficial Microbes for Alleviating Salinity Stress (Hirst et al., 2024, HortTechnology)**
    a. Demonstrated the ability of selected microbes to mitigate salinity stress in hydroponic lettuce and pak choi.
    b. Provided immediate solutions for improving crop resilience in saline environments.
13. **Leaf Anthocyanin Concentrations and Light Effects (Palsha et al., 2024, Horticulturae)**
    a. Explored how light exposure influences anthocyanin accumulation in lettuce leaves.
    b. Suggested strategies for enhancing nutritional and aesthetic value through lighting control.

3.B. Outputs:

From the Ferrarezi Lab:

- **Mayorga et al. (2024, Frontiers in Plant Sciences) and Palsha et al. (2024, Agronomy)** published articles on optimizing lighting strategies for hydroponic lettuce production, focusing on reducing energy costs by adjusting daily light integrals and improving light use efficiency in controlled-environment agriculture.
- **Mayorga et al. (2024, Horticulturae) and Palsha et al. (2024, HortScience)** published articles on the effects of light intensity and nutrient levels on hydroponic lettuce growth, providing data-driven recommendations for optimizing morphology, physiology, and production efficiency.
- **Palsha et al. (2024, Horticulturae)** explored how light exposure influences anthocyanin accumulation in lettuce leaves, suggesting strategies to enhance nutritional and aesthetic value through precise lighting control.
- **Sharkey et al. (2024, Agriculture) and Hirst et al. (2024, HortTechnology)** published research on optimizing nutrient and microbial interactions in hydroponic systems, modeling nitrogen uptake in Bibb lettuce and demonstrating how beneficial microbes can alleviate salinity stress in lettuce and pak choi.
- **Wacker et al. (2024, Sensors)** published two articles on cost-effective imaging solutions for plant research, validating an in-house imaging system for petunia analysis and developing an automated low-cost multispectral imaging system for canopy size and pigmentation analysis.
- **Iradukunda et al. (2024, Sensors)** published three articles showcasing advanced imaging techniques for seed quality assessment, including automated imaging for GA3 effects on salt-stressed lettuce, imaging for seed aging and vigor analysis, and a low-cost tool for evaluating lettuce germination and seedling vigor.
- **Thies et al. (2024, Horticulturae)** examined the interactive effects of light and temperature on wheat and rice growth under controlled conditions, providing insights for optimizing cereal crop production in controlled-environment agriculture.

From the Schoeller Lab:

- **Schoeller et al. (2024, J. Insect Sci.)** Investigated a new biological control agent that shows promise for many insect pest species such as thrips and spider mites. This research also demonstrated it was an excellent whitefly predator as well. It is now being commercialized to be sold in Europe and the U.S. for greenhouse pest management.
- **Park et al. (2025, Biol. Control)** Further developed a papaya banker plant system for indoor vegetable crops, particularly tomatoes, that added a new biological control agent *Delphastus pallidus* that improves the control that was achieved by *Encarsia sophia* and shows its broader efficacy on more whitefly species.
- **Vavilapalli et al. (2025, In Review)** Provided a comprehensive review of the global pest status of the new invasive species in the U.S., *Thrips parvispinus*, and summarized its biology, ecology, and control. Future research insights for this pest are presented.

3.C. Activities:

From the Ogden Lab:

1. **Presented a talk on Breeding Cucurbits for Controlled Environment Agriculture** at the 2024 Joint Workshop on Sustainable Development and Controlled Environment Agriculture, Charleston, SC, sponsored by USDA, DoE, and NASA. July 10, 2024.

2. **Organized and executed the 1st UGA Griffin CEA Growers Day.** Invited industry stakeholders to attend a one-day event consisting of CEA related talks by faculty and post-doctoral researchers, facility tours, and an industry needs listening session. October 16th 2024.
3. **Presented a talk called "Breeding vegetable crops for Controlled Environment Agriculture: A New Horizon" at Southeastern Fruit and Vegetable Growers Association annual meeting.** Part of a CEA session that included presentations from other UGA CEA team members. Savannah, GA. January 17th 2025.

From the Schoeller Lab:

The CEA Integrated Pest Management Lab interacted with over 15 unique CEA growers in Georgia and visited their facilities to determine pest management issues and needs. We also participated in the 1st Annual UGA Griffin CEA Growers Day, where industry representatives were hosted for listening sessions and given tours of UGA facilities.

Contributed to the following presentations/panels:

1) **Schoeller E. N.** 2025. Integrated Pest Management in Controlled Environment Vegetables. Southeast Regional Fruit & Vegetable Conference. (*oral presentation*).

2) **Schoeller E. N.** 2025. The Invasive Pepper Thrips: What Do We Know and What's at Stake? Growing Wisconsin Conference. (*oral presentation*).

3) **Schoeller E. N.** 2025. Management of Fungus Gnats and Shore Flies in Protected Agriculture. Environmental Protection Agency IPM Webinar. (*oral presentation*).

4) **Schoeller E. N.**, Fields A, Seals C 2025. Mastering Integrated Pest Management: Best Practices for CEA Success. Indoor Agcon. (*panel oral presentation*).

5) **Schoeller, E. N.** 2024. Integrated Pest Management within Controlled Environments. Southeast Small Farm Business Training Conference. (*oral presentation*).

6) **Schoeller, E. N.** 2024. *Franklinothrips vespiformis*: A Promising Biocontrol Agent for Whiteflies and Other Pests of Southeastern Greenhouses. Entomological Society of America Southeastern Branch Meeting. (*oral presentation*).

7) **Schoeller, E. N.,** P. Yu, S.V. Joseph, and M.T. Martin. 2024 *Thrips parvispinus*: Managing the Threat Panel. Southeast Green. Georgia Green Industry Association. (*panel oral presentation*).

8) **Schoeller E. N.**, A. Wright, ML Lewis Ivey, J. Marlier 2024. Effective Insect Pest and Plant Pathogen Management in Controlled Environment Agriculture. Controlled Environment Agriculture Summit East. (*panel oral presentation*).

9) **Schoeller E. N.** 2024. Advancing CEA Integrated Pest Management: A Rapidly Growing Industry. Entomological Society of America National Meeting. (*oral presentation*).

10) **Schoeller E. N.** 2024. *Thrips parvispinus*: A Looming Threat to Horticultural Production. Michigan Greenhouse Growers EXPO. (*oral presentation*).

11) **Schoeller E. N.** 2024. Enhancing Biological Control with Banker Plants and Supplemental Foods. Michigan Greenhouse Growers EXPO. (*oral presentation*).

Gave the Following Interviews for Popular Press Publications:

1) Produce Grower Magazine. Interview with Kelli Rodda, “Questions with Erich Schoeller”. Published on January 29, 2025. (Interview URL)

2) Greenhouse Product News. Interview with Madi Schafer, “UGA’s Erich Schoeller discusses thrips threats and boosting biological control at the Great Lakes EXPO”. Published on November 10, 2024. (Interview URL)

From the Kashyap Lab:

The Urban and Controlled Environment Pathology Lab (U-CEP) extended technical support to 15 urban and controlled environment agriculture (CEA) facilities across Georgia. As part of the lab’s ongoing research, surveys, and diagnostic efforts, the lab processed and analyzed over 40 plant samples. These samples were either submitted through the University of Georgia's Department of Plant Pathology's Plant Disease Clinic (*PClinic*) service or actively sampled by the U-CEP lab as part of CEA facility surveys. Diagnostic recommendations were provided by samples contributing to timely and informed plant disease management decisions for diverse urban and CEA production systems.

Outreach and Academic Presentations/Talks:

12) **Kashyap, R. (2024).** Forging Collaborative Solutions: Plant Disease Management in Urban & Controlled Environments, August 21, 2024, NE ANR Update, Oconee County.
13) **Kashyap, R. (2024).** Navigating Plant Disease Challenges in Urban & CEA Systems. In Urban Ecology Seminar Series, University of Tennessee at Chattanooga. October 11, 2024 *(Invited)*
14) **Kashyap, R. (2024).** Integrated Pathogen Management in Urban & Controlled Agriculture: A Research and Extension Initiative, October 16, 2024. CEA Growers Day - Griffin.
15) **Kashyap, R. (2024).** Integrated Plant Disease Management Solutions for Georgia's Urban and Controlled Agriculture, December 11, 2024. NW ANR update, Spalding County.

16) Reyes, J., & **Kashyap, R. (2025)**. Vegetable Disease Management under CEA. In Southeast Regional Fruit and Vegetable Conference 2025. January 2025, Savannah.
17) **Kashyap, R. (2025).** Tackling Plant Diseases in Urban and Controlled Environments: Integrated Approaches. Green GTBOP Webinar Series. March 13. 2025.
18) **Popular press internet extension publication:** Martinez-Espinoza, A., **Kashyap, R**., & Hibbs, G. (2024). Spring dead spot diagnosis and management: Fall is the time to act. https://site.caes.uga.edu/entomologyresearch/2024/10/spring-dead-spot-diagnosis-and-management-fall-is-the-tine-to-act/

3.D. Milestones:

The Ferrarezi Lab graduated 9 graduate students in the period and completed multiple grants that resulted in 15 referred papers.

The Ogden Lab Hired its first PhD student, who conducted a research experiment in his first semester on greenhouse parthenocarpic zucchini production. Hired a post-doctoral researcher who is conducting research on grafting, tomato yellow leaf curl virus, powdery mildew resistance in Cucurbits and tomato yellow leaf curl virus (TYLCV).

The Song Lab offered two M.Sc graduate students, one PhD student, and one post-doc research associate to join my group. Our team will work on the development of automated plant phenotyping platforms as well as data mining algorithms to extract key phenotypic traits that are associated with the mineral nutrient condition and genotypic information of several types of CEA crops.

The Schoeller Lab Hired a Ph.D. student to work on integrated pest management of Thrips parvispinus in protected agriculture. Hired a Ph.D. student to work on greenhouse lighting effects on arthropod population dynamics. Sponsored a visiting scholar to work on plant-mediated interactions between endophytes and insect herbivores.

The Kashyap Lab Hired a post-doctoral researcher who is conducting survey and sampling across different urban and controlled environment facilities across Georgia, to characterize fungal and oomycete plant pathogens associated with food crops grown in these systems, in addition to determining the critical control points of hazard contaminations.

4. **Impact Statements**.

Research on the Ferrarezi Lab has provided data-driven insights into optimizing lighting, temperature, nutrient management, and imaging technologies for hydroponic and greenhouse crop production. Studies on light intensity and daily light integral (DLI) have shown that lowering DLI by 20–30% can reduce energy costs while maintaining lettuce biomass production. Adaptive lighting strategies have improved light use efficiency by up to 25%, while targeted potassium adjustments have enhanced lettuce morphology and physiology. Nutrient uptake modeling has predicted nitrogen absorption rates with over 90% accuracy, contributing to precision fertigation strategies in vertical farming. Beneficial microbes have reduced salinity

stress effects by up to 40% in hydroponic lettuce and pak choi. Additionally, cost-effective imaging systems have been validated for plant phenotyping, canopy size analysis, and stress response assessment, reducing imaging costs by more than 50% compared to commercial alternatives. These advancements equip commercial growers and researchers with actionable strategies to improve crop quality, optimize resource use, and enhance efficiency in controlled environments. By integrating these findings, growers can increase yields by 10–15%, lower input costs, and improve sustainability in indoor and greenhouse production systems.

The Ogden lab established new locations for plant breeding including inside of two small greenhouse compartments (each 6.4 m X 7.3m), an unheated polytunnel, and a nursery pad. In muskmelon, breeding efforts focused on marker assisted selection for disease resistance loci like Fusarium and powdery mildew, selection for main-stem fruiting, and greenhouse performance. Novel types of melon including Korean and Japanese melons are being crossed with traditional cantaloupe and honeydew with the goal of breeding new types of melons with superior performance inside greenhouses, improved flavor, good disease resistance and striking outward appearances. Breeding efforts in greenhouse summer squash cultivar development continued by focusing on plant architecture, powdery mildew resistance, and new efforts to incorporate parthenocarpic genes to ease the need for pollination inside of greenhouses. A new program was initiated in tomato to breed dwarf/compact tomato plants with improved flavor, enhanced fruit size, and increased anthocyanin content. Such cultivars could have utility in small spaces found in vertical farms, and other CEA systems. Grafting is being explored as a tool for promoting cold tolerance in cucumber to help ease heating costs and for promoting yield and fruit quality in muskmelon.

The Song Lab was established in late November 2024. Our research focuses on the development of the next generation of plant phenotyping technologies in CEA. The vision of our team is to develop and provide state-of-the-art tools, from hardware to software, robotics to AI, to the broader community of crop studies, serving multiple purposes, including accelerating plant breeding, early identification of biotic and abiotic stresses, real-time crop biomass monitoring, and the association of genomics and phenomics. We have been actively exploring opportunities and establishing connections with growers and researchers in several symposiums and conferences, such as the Southeast Regional Fruit and Vegetable Conference and the Urban Mushroom Symposium at the UGA Urban Ag Center. Ongoing research includes:

a. The development of a high-throughput, high-precision, and automated peanut maturity evaluation system through hyperspectral imaging. This user-friendly tool is designed to help growers accurately and rapidly assess peanut maturity, empowering them to optimize harvest timing—a decision with multi-million-dollar economic implications in Georgia. The system is also designed to be deployed in greenhouses, where breeders will be able to easily collect peanut phenotypes.
b. The development of an automated watermelon traits extraction toolbox using AI-based computer vision. This project aims to improve or potentially replace the current manual work of labeling watermelon fruit structures on an image of the cross-section. This will help our collaborators save a lot of labor and collect way more types of phenotypic data than the traditional manual method.

The Kashyap Lab initiated statewide sampling and surveys to assess current plant pathogen challenges and characterize fungal and oomycete populations associated with edible crops in controlled environment agriculture (CEA). In addition, the lab's efforts include sampling substrates, surfaces, water, and other high-risk points to better understand critical control points within these systems. As a relatively new lab, established less than a year ago, it has already

been able to identify common disease challenges such as root rots and soft rots, and detect prominent pathogens including *Pythium*, *Botrytis*, and powdery mildews through these preliminary surveys. Ongoing efforts are focused towards developing integrated management strategies against these pathogens.

The Schoeller Lab initiated three new projects involving 1) greenhouse LED wavelength effects on arthropod populations; 2) control of the new invasive horticultural pest species in the U.S., *Thrips parvispinus* (Karny) (Thysanoptera: Thripidae), in protected agriculture; and 3) plant-mediated interactions between endophytes and insect herbivores. Project 1 was initiated because artificial lighting has been shown to impact the behavior and dispersal of insects through differential light intensities, wavelengths, and photoperiods. The narrow wavelength range selection possible with LEDs opens the possibility for selecting wavelengths that pests or natural enemies are most sensitive to and exhibit the strongest phototactic behaviors. This may have utility for manipulating predator-prey interactions within the crop in beneficial ways, such as repelling pests from the crop, reducing their feeding activity/fitness, or pests to areas of the crop where mortality rates can be increased. It is necessary to examine how pests and biological control agent populations perform under different light regimes to tailor management strategies for maximum control. Project 2 was initiated because *T. parvispinus* poses a serious threat to global horticultural production, including nursery and greenhouse ornamental crops, as well as field and indoor grown vegetables. The concern over its potential negative economic impact on these crops is growing within its recently invaded range, such as the USA and Canada. Research in management strategies for *T. parvispinus* will focus on physical, cultural, chemical, and biological control methods. Project 3 was initiated because fungal entomopathogens play important roles as endophytes that protect plants from a wide spectrum of biotic stress like pathogens and insect herbivores. Investigating these interactions could shed light on novel strategies to enhance crop resilience, particularly in the context of sustainable agricultural practices

5. **Published Written Works**.

From the Ferrarezi Lab:

Refereed

1) Mayorga, A.; van Iersel, M. W.; **Ferrarezi, R. S.*** 2024. Lowering the target daily light integrals following days with excessive lighting can reduce lettuce production costs. *Frontiers in Plant Sciences* 15: 1467443. DOI: 10.3389/fpls.2024.1467443

2) Silva, J. A. O. S.; Siqueira, V. S. de; Mesquita, M.; Vale, L. S. R.; Silva, J. L. B. da; Silva, M. V. da; Lemos, J. P. B.; Lacerda, L. N.; **Ferrarezi, R. S.*;** Oliveira, H. F. E. de. 2024. Artificial intelligence applied to support agronomic decisions for the automatic aerial analysis images captured by UAV: A systematic review. *Agronomy* 14(11): 2697; DOI: 10.3390/agronomy14112697

3) Palsha. P. L.; van Iersel, M. W.; Dickson, R. W.; Seymour, L.; Yelton, M.; **Ferrarezi, R. S.*** 2024. Strategic light use efficiency optimization of hydroponic lettuce exposed to different photosynthetic photon flux densities. *Agronomy* 14(10): 2281. DOI: 10.3390/agronomy14102281

4) Wacker, K.; Kim, C.; van Iersel, M. W.; Haidekker, M.; Seymour, L.; **Ferrarezi, R. S.*** 2024. Validation of in-house imaging system via code verification on petunia images collected at increasing fertilizer rates and pHs. *Sensors* 24(17): 5809. DOI: 10.3390/s24175809

5) Mayorga, A.; van Iersel, M. W.; **Ferrarezi, R. S.*** 2024. Varying light intensities affect lettuce growth and physiology in controlled indoor environments. *Horticulturae* 10(9): 931. DOI: 10.3390/horticulturae10090931

6) Wacker, K.; Kim, C.; van Iersel, M. W.; Sidore, B.; Pham, T.; Haidekker, M.; Seymour, L.; **Ferrarezi, R. S.*** 2024. Development of an automated low-cost multispectral imaging system to quantify canopy size and pigmentation. *Sensors* 24(17): 5515. DOI: 10.3390/s24175515

7) Sharkey, A.; Altman, A.; Cohen, A. R.; Groh, A. A. T.; Igou, T.; **Ferrarezi, R. S.**; Chen, Y. 2024. Modeling Bibb lettuce nitrogen uptake and biomass productivity in vertical hydroponic agriculture. *Agriculture* 14(8): 1358. DOI: 10.3390/agriculture14081358

8) Thies, M.; **Ferrarezi, R. S.***; Realff, M. 2024. Combined effect of light and temperature on wheat and rice growth: A case study in controlled environment agriculture. *Horticulturae* 14(8): 1641. DOI: 10.3390/agronomy14081641

9) Palsha. P. L.; van Iersel, M. W.; Dickson, R. W.; Seymour, L.; Yelton, M.; **Ferrarezi, R. S.*** 2024. Morphological and physiological changes of hydroponic lettuce grown in varying potassium concentrations and an adaptive lighting control system. *HortScience* 59(8): 1097-1105. DOI: 10.21273/HORTSCI17806-24

10) Iradukunda, M.; van Iersel, M. W.; Seymour, L.; Lu, G.; **Ferrarezi, R. S.*** 2024. Automated imaging to evaluate the exogenous gibberellin (GA_3) impact on seedlings from salt-stressed lettuce seeds. *Sensors* 24(13): 4228. DOI: 10.3390/s24134228

11) Iradukunda, M.; van Iersel, M. W.; Seymour, L.; Lu, G.; **Ferrarezi, R. S.*** 2024. The use of imaging to quantify the impact of seed aging on lettuce seed germination and seedling vigor. *Sensors* 24(13): 4235. DOI: 10.3390/s24134235

12) Iradukunda, M.; van Iersel, M. W.; Seymour, L.; Lu, G.; **Ferrarezi, R. S.*** 2024. Low-cost imaging to quantify germination rate and seedling vigor across lettuce cultivars. *Sensors* 24(13): 4225. DOI: 10.3390/s24134225

13) Hirst, A.; Anee, S. A.; Housley, M. J.; Qin, K.; **Ferrarezi, R. S.*** 2024. Selected Beneficial microbes alleviate salinity stress in hydroponic lettuce and pak choi. *HortTechnology* 34(3): 345–352. DOI: 10.21273/HORTTECH05403-24

14) Palsha. P. L.; van Iersel, M. W.; Dickson, R. W.; Seymour, L.; Yelton, M.; **Ferrarezi, R. S.*** 2024. Exploring leaf anthocyanin concentrations and light effects on lettuce growth. *Horticulturae* 10(5): 437. DOI: 10.3390/horticulturae10050437

15) Vosburg, C.; Sinn, J. P.; Orbovic, V.; **Ferrarezi, R.S.**; Zapien-Macias, J. M.; Taylor, E. L.; Hilf, M.; McCollum, G.; Gottwald, T. R.; Stover, E.; McNellis, T. W. 2024. Assessment of grapefruit expressing anti-NodT antibody for Huanglongbing resistance. *PhytoFrontiers* 4(2): 172-182. DOI: 10.1094/PHYTOFR-06-23-0078-R

Abstracts

1) Subedi, B. S.; **Ferrarezi, R. S.**; Pandey, S.; Ogden, A. 2025. Response of three parthenocarpic zucchini cultivars to different substrates in greenhouses. *Proceedings.* 2025 Southern Region American Society for Horticultural Science, Feb 3rd, 2025. Las Colinas/TX, USA.

2) Colvard, A.; **Ferrarezi, R. S.** 2024. Designing & building a high-tech small-scale vertical farm for residences. *Proceedings.* 2024 AgTech Research and Extension for Emerging Undergraduates Program Presentation, Jul 25th, 2024. Athens/GA, USA.

3) Thompson, B.; Housley, M. J.; Qin, K.; **Ferrarezi, R. S.** 2024. Enhancing rose propagation using moisture sensor-controlled irrigation and LED supplemental lighting in greenhouses. *Proceedings.* 2024 AgTech Research and Extension for Emerging Undergraduates Program Presentation, Jul 25th, 2024. Athens/GA, USA.

4) Lariscy, E.; Housley, M. J.; **Ferrarezi, R. S.** 2024. Light intensity and composition for production of *Catharanthus roseus* in vertical farms as a source of biopharmaceuticals. *Proceedings.* 2024 AgTech Research and Extension for Emerging Undergraduates Program Presentation, Jul 25th, 2024. Athens/GA, USA.

5) Howell, E.; Housley, M. J.; **Ferrarezi, R. S.** 2024. Hydroponic system comparison for *Catharanthus roseus* production for extraction of biopharmaceutical secondary metabolites. *Proceedings.* 2024 AgTech Research and Extension for Emerging Undergraduates Program Presentation, Jul 25th, 2024. Athens/GA, USA.

6) Phan, P.; Housley, M. J.; **Ferrarezi, R. S.** 2024. Designing and building a high-tech small-scale vertical farm for residences. *Proceedings.* 2024 AgTech Research and Extension for Emerging Undergraduates Program Presentation, Jul 25th, 2024. Athens/GA, USA.

7) Finnell, N.; **Ferrarezi, R. S.** 2024. Developing low-cost residential vertical gardening system. *Proceedings.* 2024 AgTech Research and Extension for Emerging Undergraduates Program Presentation, Jul 25th, 2024. Athens/GA, USA.

8) McElhannon, D.; Nam, S.; **Ferrarezi, R. S.** 2024. Reducing energy costs in greenhouse supplemental lighting for basil production using “daily light integral carry-over” method. *Proceedings.* 2024 UGA CAES Young Scholars Program Presentation, Jul 12th, 2024. Athens/GA, USA.

9) Towner, M.; Rauf, H.; **Ferrarezi, R. S.** 2024. Evaluating growth responses of different lettuce cultivars under varying nutrient sufficiency ranges for sap analysis recommendations. *Proceedings.* 2024 UGA CAES Rising and Emerging Scholars Program Presentation, Jul 18th, 2024. Athens/GA, USA.

10) Locatelli, S.; Nicoletto, C.; Zanin, G.; Sambo, P.; **Ferrarezi, R. S.** 2024. Resistenza allo stress termico in piantine da vivaio tramite inoculo di funghi endofiti. *Proceedings.* II Convegno Nazionale di Orticoltura e Floricoltura. Jun 19th, 2024. Padova/Emilia Romana, Italy.

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