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Research Paper

Growing Safer Greens: Exploring Food Safety Practices and Challenges in Indoor, Soilless Production Through Thematic Analysis of Leafy Greens Grower Interviews

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ABSTRACT

Indoor, soilless production—often referred to more broadly as controlled environment agriculture (CEA)—is increasingly used for the cultivation of leafy greens. Minimal information is currently available regarding food safety practices during production and distribution of leafy greens grown within indoor, soilless environments in the United States (U.S.). This study aimed to describe production challenges and implementation of good agricultural practices among CEA growers. Data collection methods included semi-structured interviews (N = 25) and a supplemental online survey completed by growers (N = 12) in the U.S. Out of 18 total responses (i.e., multiple responses allowed per completed survey), survey data indicated that lettuce (*n* = 5; 27.8%) was the most commonly grown leafy green, followed by culinary herbs (*n* = 3; 16.7%) and arugula (*n* = 3; 16.7%). Most growers (*n* = 7; 58.3%) grew other agricultural products, specifically other crops in addition to leafy greens. Revenue from sales ranged from <US$25 000 to >US$500 000 per year. Meanwhile, nearly half (*n* = 5; 45.5%) of respondents (N = 11) were uncertain whether their produce was subject to the FSMA Produce Safety Rule. Most survey respondents used vertical farming techniques (5 out of 11; 45.5%) or some variety of greenhouse (4 out of 11; 36.4%). Based on 35 total responses, leafy greens were most commonly sold to "Commercial Restaurants" (*n* = 7; 20.0%), "Grocery Stores" (*n* = 7; 20.0%), "Institutional Foodservice Establishments (hospitals, schools, childcare, long-term care)" (*n* = 6; 17.1%), and "Wholesaler/Distributers" (*n* = 6; 17.1%). The 11 interview questions elucidated three major themes: contextual, barriers to risk management and regulatory compliance, and research needs. Thirteen subthemes were identified, and an example of a subtheme within each major theme, respectively, includes worker hygiene and training, regulatory and certification environment, and risk assessments of individual issues.

Controlled environment agriculture (CEA) aims to provide an optimal growing environment for plants, thereby maximizing their potential for yield, quality, and nutritional value, while minimizing the use of resources such as water, energy, and land (Benke & Tomkins, 2017; Engler & Krarti, 2021). This method typically involves the use of technologies such as climate control, artificial lighting, an array of "ponic" systems (e.g., hydroponic, aeroponic, aquaponic), and precision irrigation. CEA represents a significant advancement in agricultural technology, with the potential to revolutionize food production systems globally. The use of a controlled environment enables growers to overcome many of the challenges associated with conventional, field-based agriculture, such as the limitations imposed by changing weather conditions, pests, and diseases (Benke & Tomkins, 2017; Engler & Krarti, 2021). CEA systems can vary widely in scale, from small-scale urban farms to large commercial operations, and can be tailored to suit a range of crops and growing conditions (Yuan et al., 2022). In addition, advances in technology have enabled the development of new CEA methods, such as aeroponics (Rakib Uddin & Suliaman, 2021), fogponics (Rakib Uddin & Suliaman, 2021), and bioponics (Wongkiew et al., 2022) offering even greater control over growing conditions and resource usage. As such, the potential for CEA to contribute to sustainable food production and address global food security challenges is immense.

Hydroponics and Aquaponics. Two popular types of CEA are hydroponics and aquaponics, which both involve growing plants in systems containing nutrient-rich solution without the use of soil. This method of agriculture eliminates the need for soil, which can reduce the amount of water needed for irrigation and allows for more precise

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control over the plant's growing environment. The roots of the plants are either suspended in the nutrient solution or in a soilless medium, such as peat/perlite mixes or coconut coir (Jordan et al., 2018). Popular types of hydroponic systems include deep water culture, nutrient film technique, ebb and flow, drip irrigation, and wick irrigation (Sharma et al., 2018).

Aquaponics is an innovative agricultural system that integrates the principles of aquaculture and hydroponics to create a closed-loop ecosystem. At its core, aquaponics involves the cultivation of fish in tanks, with the nutrient-rich water from the fish tanks being used to grow plants in a soil-free system. Typically, in aquaponics systems, fish waste solids are removed through a series of filtering steps, and then, the nutrient-rich water is utilized for plant growth. This process results in the elimination of harmful substances, and the clean water is returned to the fish tanks, resulting in a symbiotic relationship between the fish and the plants. Aquaponic systems can allow for highly efficient plant growth and nutrient cycling, while also reducing water usage and minimizing waste. Furthermore, aquaponic farmers have the added benefit of being able to sell the fish once they reach maturity, providing an additional source of income (Jordan et al., 2018).

Fresh Produce Safety and Soilless, Indoor Production. Alegbeleye and colleagues (2018) have noted that soil and irrigation water are recognized as key sources of contamination for conventionally grown fresh produce. In the U.S., fresh produce has been identified as the source of approximately 13% of foodborne outbreaks between 2010 and 2017 (Carstens et al., 2019). Similarly, in Europe, produce was implicated in 10% of foodborne outbreaks from 2007 to 2011, and fresh produce accounted for 35% of hospitalizations and 46% of deaths attributed to foodborne diseases, indicating a higher risk compared to other food categories (EFSA, 2018). More specifically, leafy greens are often implicated in foodborne disease transmission with 78 outbreaks reported to the U.S. Centers for Disease Control and Prevention (CDC) from 2014 to 2021 (CDC, 2023). Prior to 2014, Herman et al. (2015) analyzed leafy greens-associated outbreaks in the U.S. from 1973 to 2012 and identified 606 outbreaks. The most common pathogens responsible for these outbreaks include Hepatitis A, human norovirus, *Escherichia coli* O157:H7, *Campylobacter, Shigella sonnei, Listeria monocytogenes,* and *Salmonella* among others (Herman et al., 2015). These findings underscore the need for improved or alternative (e.g., indoor, soilless cultivation) methods of food production that reduce the risk of contamination and enhance food safety.

Cross-contamination is a primary cause of pathogen contamination in fresh produce and is often water-mediated (Possas & Pérez-Rodríguez, 2023). Similarly, Wang and Teplitski (2023) found that preharvest environmental and production factors impact food safety outcomes. Notably, one foodborne disease outbreak has been linked to leafy greens from a CEA facility. In 2021, 31 people became ill and four were hospitalized due to *Salmonella* Typhimurium transmitted by lettuce grown in a CEA facility using deep water culture and floating raft production methods (CFSAN, 2022; McClure et al., 2023). CEA-grown leafy green products have also been linked to at least 15 product recalls across the U.S. and Canada since 2018 due to potential contamination with bacterial pathogens (FDA, 2023; Misra & Gibson, 2020).

Aim and Motivation. The primary aim of this investigation was to identify the various obstacles encountered by CEA operations in their implementation of the key requirements outlined in the Food Safety Modernization Act (FSMA) Final Rule on "Standards for the Growing, Harvesting, Packing, and Holding of Produce for Human Consumption" or the Produce Safety Rule (PSR) (FDA, 2015). While not all CEA operations are covered under the PSR (e.g., < $25 000 in annual revenue or qualified exempt), characterizing their understanding and implementation of Good Agricultural Practices (GAPs)—the foundation of the PSR—is still critical to ensuring fresh produce safety. The data collection process using a survey instrument and transcripts from semi-structured interviews encompassed a comprehensive analysis of various aspects of CEA operations, including their production practices, business operations, farm characteristics, employee training requirements, and research needs to ascertain the food safety challenges faced in the cultivation and sale of leafy greens. The outcome of this study enabled a detailed examination of the practices adopted by indoor, soilless leafy green operations in the U.S. with the aim of providing valuable insights regarding future research directions to address the needs of this specific sector of the CEA industry.

Materials and methods

Ethics Statement. The University of Arkansas Institutional Review Board (Protocol No: 2302455435) reviewed the study and granted an exemption. The online survey included a cover page outlining the research objectives and required participants to answer a consent question before starting. The survey did not collect any personal identifying information, such as participant name, street address, phone number, or email address, but did collect data about the state location of each grower to evaluate geographic distribution. Prior to conducting semi-structured interviews, participants were emailed a consent letter and asked if they had reviewed the consent letter and then a verbal "yes" was given in order to proceed with the interview.

Rationale and Recruitment. The study methodology was adopted to identify specific food safety challenges faced by CEA leafy green producers as well as potential barriers to implementing recommended good agricultural practices through both survey data and semi-structured interviews. This approach was used to gain a comprehensive understanding of CEA leafy green growing practices and to identify current knowledge and future research needs relevant to microbial contamination risks during indoor leafy green production. The study included CEA produce growers from across the continental United States (Fig. 1).

Convenience sampling was used to recruit participants from a comprehensive list of CEA growers. This list was initially compiled by the Ohio Controlled Environment Agriculture Research Center located at The Ohio State University in Columbus, OH through formation of the CEA Extension Network. Briefly, both research and extension personnel with a focus on CEA were contacted to identify CEA operations in their respective states, and these operations were added to a master Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, WA). From this spreadsheet, the authors of the current study performed additional web searches on google.com (Google LLC, Mountain View, CA) to find operations in states that were not represented and added these operations to the master Excel spreadsheet. The final list included 177 CEA operations across 47 states and the District of Columbia after accounting for operations no longer in business or incorrect contact information (i.e., email bounce back). Growers were contacted via email, company website contact forms, or direct message on Instagram, LLC (Meta Platforms, Menlo Park, CA) or LinkedIn (LinkedIn Corporation, Sunnyvale, CA) to gauge their interest in participating in the study. To qualify for the study, growers had to have an active indoor, soilless leafy green growing operation and sell their product to customers (i.e., not growing solely for personal use).

Survey Structure. The Qualtrics platform (Qualtrics, Seattle, WA) was utilized to conduct a survey with 18 items (Table 1). The survey was designed to include both open-ended and closed-ended questions, with the option to enter responses under "other". The survey was developed using items from a survey validated previously by Misra and Gibson (2021) and utilized by Hamilton and colleagues (2023). The survey was internally and externally validated previously by food safety experts and indoor produce growers, with face validity and content validity checked in accordance with Litwin and Fink (1995). The question wording and appropriateness of questions were reviewed by a food safety education and outreach expert. The survey was initially

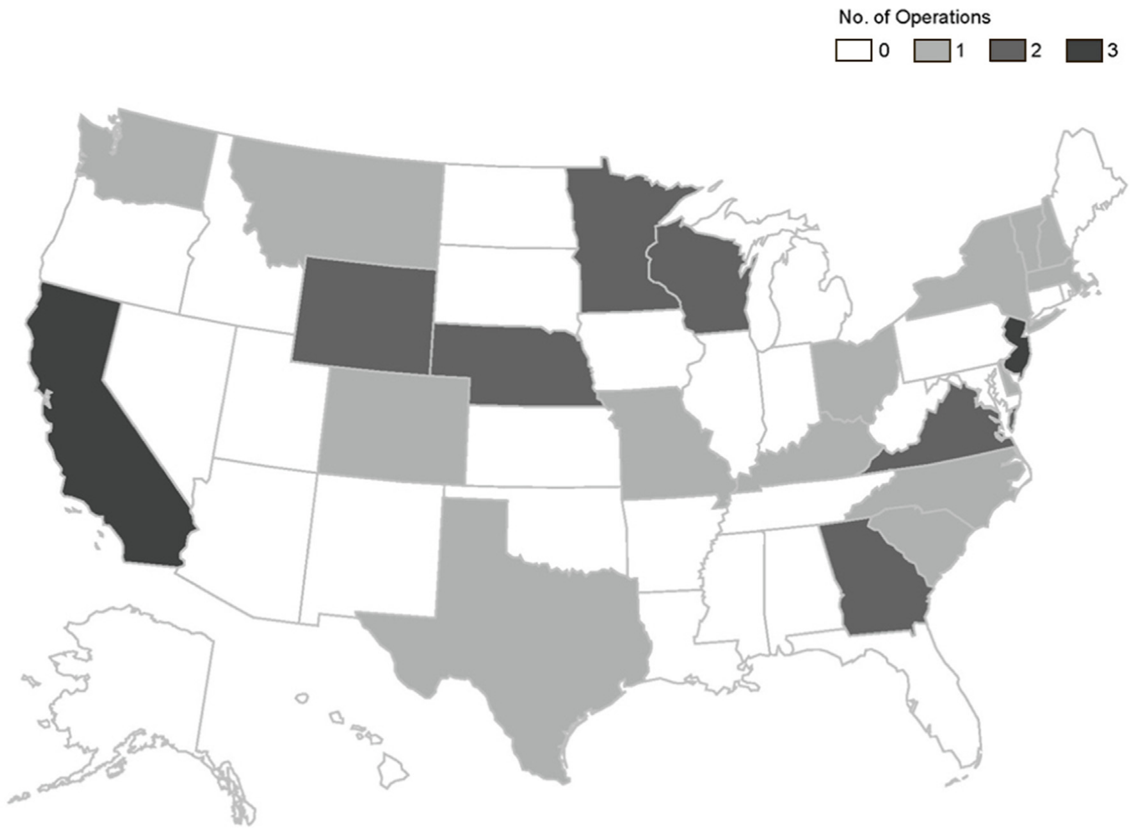

Figure 1. Map of participating indoor, soilless leafy greens growing operations.

tested by three graduate students who provided predetermined responses to evaluate its ease of use. Based on discussions with indoor produce growers concerning their understanding of the survey items, modifications were subsequently made (Misra & Gibson, 2021).

Semi-structured Interviews. All interviews were conducted by a Ph.D.-trained interviewer via Zoom (Zoom Video Telecommunications, San Jose, CA), Microsoft Teams (Microsoft Corporation, Redmond, WA), or telephone, depending on the participant's preference and internet availability. The interviewer provided an introduction to the study and asked the 11 questions listed in Table 2, along with additional clarifying questions when necessary. Zoom and Microsoft Teams recordings were autotranscribed using audio transcription services available on each software platform. Telephone interviews were recorded using Rev Call Recorder for iOS version 2.6 (Rev, Austin, TX), and audio files were then sent to Scribie (CGBiz Corporation, San Francisco, CA) for automated verbatim transcription.

Data Analysis and Interpretation. The analysis of the survey data was conducted using R Studio (R Studio, 2020; R Core Team, 2022) with the base (Wickham, 2016) with data directly imported from the Qualtrics platform (Qualtrics). Location data were imported to JMP Pro 17 (SAS Institute, Cary, NC) and plotted to show geographic distribution. The transcripts from the semi-structured interviews were analyzed using the emergent thematic approach to identify key themes. Two independent researchers coded the transcripts and identified themes into nonmutually exclusive categories (Lune & Berg, 2017). The researchers then met to discuss and merge the identified themes. A constant comparison approach was used to identify broad themes across all interviews. The themes were divided into three categories: contextual (physical and operational attributes that could impact implementation of practices), barriers to risk management and regulatory compliance (physical or education barriers to safely growing produce or complying with regulations), and research needs (information desired by the growers) (Hamilton et al., 2023). The survey and the semi-structured interviews were completed by twelve participants, while twenty-five participants completed the semi-structured interviews.

Results

Survey Results. Results of the survey instrument are listed in Table 1. Each participant received a unique survey link generated in Qualtrics to avoid the completion of duplicate responses. Notably, only 12 of 25 growers completed the survey, so a good portion of data is missing. For example, from the interviews, it is known that at least four growers utilized aquaponic systems, yet none completed the survey. Out of 18 total responses (i.e., multiple responses allowed per completed survey), the most commonly grown leafy green was "lettuce" (n = 5; 27.8%) (there were many varieties), followed by culinary herbs (such as basil) (n = 3; 16.7%) and arugula (n = 3; 16.7%), and then microgreens (n = 2; 11.1%). Leafy greens were not the only agricultural product grown by the majority of respondents (n = 7; 58.3%). All respondents (n = 6) who completed the follow-up question grew other crops in addition to leafy greens.

Leafy greens growers (11 out of 12 answered) were somewhat uncertain if their produce was subject to the PSR: "I don't know" (n = 5; 45.5%). Although further explored in the Discussion, regulatory requirements were a source of confusion for growers due to a perceived lack of alignment across regulatory/inspection bodies. Most growers who responded (N = 11) used either vertical farming techniques (n = 5; 45.5%) or some variety of greenhouse (n = 4; 36.4%). Out of 18 responses, the most frequently held certification was the "Good Agricultural Practices (GAP) Audit" (n = 5; 29.4%) followed by "None of these" (n = 4; 23.5%). Leafy greens were sold

Table 1
Qualtrics survey questions with response summary[a]

Question		Response Type	Levels
Geographical Location			
1	Please provide the 5-digit zip code where indoor leafy greens are produced.	Numerical	Numerical
Agricultural Practices, Other Agricultural Products, and the Produce Safety Rule			
2	Do you grow indoor leafy greens?	Binary	"Yes" (n = 12; 100%) "No" (n = 0; 0%)
3	Are indoor leafy greens the only agricultural product that you grow?	Binary	"Yes" (n = 5; 41.7%) "No" (n = 7; 58.3%)
4	Please indicate type(s) of indoor produced crop. (Name of crops)[b]	Open response	"Lettuce" (n = 5; 27.8%) "Herbs" (n = 3; 16.7%) "Microgreens" (n = 2; 11.1%) "Kale" (n = 2; 11.1%) "Chard" (n = 1; 5.6%) "Arugula" (n = 3; 16.7%) "Mizuna Mix" (n = 1; 5.6%) "Spinach" (n = 1; 5.6%)
5	What are the other types of agricultural products on your farm?	3-Level Factor	"Crops" (n = 6; 100%) "Livestock" (n = 0; 0.0%) "Both" (n = 0; 0.0%)
6	Do you grow any produce covered by the Produce Safety Rule?[c]	3-Level Factor	"Yes" (n = 5; 45.5%) "No" (n = 1; 9.0%) "I don't know" (n = 5; 45.5%)
7	What type of livestock do you raise? Select all that apply.	5-Level Factor with open response	"Cattle" (n = 0; 0%) "Swine" (n = 0; 0.0%) "Small ruminants (sheep/goats)" (n = 0; 0.0%) "Fish" (n = 0; 0.0%) "Poultry" (n = 0; 0.0%) "Other" (n = 0; 0.0%)
8	In which type of system do you produce half or more of your indoor leafy greens?[c]	6-Level Factor	"Hybrid facilities (Indoor growing operation without vertical growing systems. Mid-tech glass/poly greenhouse with vertical growing systems. Greenhouse with outdoor operations.)" (n = 0; 0.0%) "Container farm (Self-contained growing units that use vertical farming and artificial lighting. In contrast to custom-designed warehouses, container farms strive for standardization.)" (n = 1; 9.0%) "Indoor vertical farm (Any fully enclosed and opaque room with a vertical hydroponic, aeroponic, and/or aquaponic system. Artificial lights are used.)" (n = 5; 45.5%) "Low-tech high tunnel (Semi-circular, tunnel-shaped structure made of steel and polythene. Little to no automation.)" (n = 1; 9.0%) "Mid-tech glass/ploy greenhouse (Transparent, enclosed structure made of glass or polycarbonate. Has more automation than high tunnel production but not to the full extent possible.)" (n = 2; 18.2%) "High tech glass greenhouse (Transparent enclosed structure made of glass. Highly dependent on automation and technology systems.)" (n = 2; 18.2%)
9	How often do you harvest leaf greens? (e.g., number of days per week)	Numerical	Mean (3.6 ± 2.1 days/week) Median (3 days/week) Minimum (1 day/week) Maximum (7 days/week)
10	How would you classify your indoor farm production system?[c]	5-Level Factor	"Use of organic practices (not certified)" (n = 5; 45.5%) "Natural" (n = 2; 18.2%) "I am not sure" (n = 0, 0.0%) "Conventional" (n = 3; 27.3%) "Certified Organic" (n = 1; 9.0%)
Business Dynamics			
11	Please indicate your role in your company.	Open Response	"Sales and Service" (n = 1; 8.3%) "Greenhouse Manager" (n = 1; 8.3%) "Owner" (n = 4; 33.3) "VP of Supply Chain" (n = 1; 8.3%) "Co-Founder" (n = 1; 8.3%) "Grower/Food Safety Officer (n = 1; 8.3%) "R&D and Head Grower" (n = 1; 8.3%) "Director of Food Safety and Quality Assurance" (n = 1; 8.3%) "VP of Food Safety and Compliance" (n = 1; 8.3%)
12	Each year, approximately how much (gross) revenue do you bring in from growing indoor leafy greens?[c]	5-Level Factor	"Less than $25 000" ($n$ = 2; 18.2%) "$25 000–$99 999" (n = 3; 27.3%) "$100 000–$249 999" (n = 2; 18.2%) "$250 000–$499 999" (n = 1; 9.0%) "Greater than $500 000" ($n$ = 3; 27.3%)
13	Does your farm have any of the following certifications? (Check all that apply)[d]	4-Level Factor with open response	"Certified Organic" (n = 1; 5.9%) "Good Agricultural Practices (GAP) Audit" (n = 5; 29.4%) "A third-party sustainability certification" (n = 2; 11.8%) "None of these" (n = 4; 23.5%) "Other (list) – 'GMP' (n = 2; 11.8%), 'Produce Safety' (n = 1; 5.9%), GFSI audit (PrimusGFS) for GAP' (n = 1; 5.9%), 'Non-GMO Project Verification Certification' (n = 1; 5.9%)"

Table 1 (*continued*)

Question		Response Type	Levels
14	How do you measure your farm's indoor leafy green production?	5-Level Factor with open response	"ounces" (n = 0; 0%) "pounds" (n = 4; 33.3%) "kilograms" (n = 2; 16.7%) "heads" (n = 5; 41.7%) "pallets" (n = 1; 8.3%) "Other (list)" (n = 0; 0%)
15	To whom do you sell your indoor leafy greens?[e]	8-Level Factor with open response	"Farmer's Markets" (n = 3; 8.6%) "U-Pick Sales" (n = 0; 0.0%) "Food Cooperative (Co-op)" (n = 3; 8.6%) "Community Supported Agriculture (CSA)" (n = 2; 5.7%) "Institutional Foodservice Establishments (hospitals, schools, childcare, long-term care)" (n = 6; 17.1%) "Commercial Restaurants" (n = 7; 20.0%) "Grocery Stores" (n = 7; 20.0%) "Wholesaler/Distributers" (n = 6; 17.1%) "Other (list) – "'Food Bank' (n = 1; 2.9%)"
16	What is the indoor leafy green production area built for?[c]	2-Factor Response	"Built for indoor farming" (n = 7; 63.6%) "Converted for indoor farming" (n = 4; 36.4%)
17	How many personnel do you have working in the production area?	Numerical	Mean (38.5 ± 66.8 persons) Median (8 persons) Minimum (2 persons) Maximum (220 persons)
18	What is the size of production area? (Acreage/ Building/Space)	Open Response	Mean (22193 ± 41241.1 sq ft) Median (3000 sq ft) Minimum (360 sq ft) Maximum (124000 sq ft)

[a] All percentages are based on N = 12 unless otherwise indicated.
[b] Multiple responses per survey allowed (N = 18).
[c] N = 11 survey responses received.
[d] Multiple responses per survey allowed (N = 17).
[e] Multiple responses per survey allowed (N = 35).

Table 2
Semi-structured interview discussion guide questions

Question No.	Question Content
1	Can you identify the top three biggest safety challenges during hydroponic of leafy greens?
2	Risk management practices for worker health and hygiene.
3	Risk management practices for agricultural water.
4	Risk management practices for soilless substrates.
5	Risk management practices for domesticated and wild animals.
6	Risk management practices for harvesting and packing activities.
7	Risk management practices for storage and transportation activities.
8	Risk management practices for equipment, tools, and building.
9	Risk management practices for traceability.
10	What would you do more to ensure the safety of crops in your production environment if you had unlimited resources?
11	Is there anything that you want to add?

through a variety of avenues with most growers selling via more than one type of venue (7 out of 11; 63.63%). Based on 35 total responses, leafy greens were predominantly sold to "Commercial Restaurants" (n = 7; 20.0%), "Grocery Stores" (n = 7; 20.0%), "Institutional Foodservice Establishments (hospitals, schools, childcare, long-term care)" (n = 6; 17.1%), and "Wholesaler/Distributers" (n = 6; 17.1%).

Respondents (N = 12) were most frequently the owner of the operation (n = 4; 33.3%), and gross revenue was evenly distributed between "Less than $25 000" to "Greater than $500 000." Most leafy green production areas were built for indoor farming, and the median number of employees working in the production area was 8 persons (min = 2 persons; max = 220 persons). The median production area was 3000 sq ft (min = 360 sq ft; max = 124 000 sq ft), and the median harvesting frequency was 3 days per week (min = 1 day/ week; max = 7 days/week).

Semi-Structured Interview Results. The average interview lasted approximately one hour (range: 23.5–63.3 min; mean: 43.9 ± 12.4 min; median: 45.1 min), and three major themes were isolated from the 11 interview questions: *contextual* (worker hygiene and training; agricultural water; growth substrates and nutrients; pests and biocontrol; harvesting, storage, and transportation; and sanitizer selection and use), *barriers to risk management and regulatory compliance* (business upgrades; regulatory and certification environment; traceability), and *research needs* (algae control; postharvest storage, treatment, and washing; risk assessments of individual issues; and training program development). Tables 3–5 present each of the three major themes, respectively, along with illustrative quotations to support these themes. Most of the growers interviewed used hydroponic systems, while a small minority (n = 4) opted for aquaponic systems, which incorporated fish, such as tilapia.

Contextual Themes. A major area of concern for many growers was related to labor factors, particularly worker training and compliance, worker retention, and developing a culture of food safety. A majority of growers faced challenges with handwashing and gloving compliance, which was a widely required practice at the operation level. Notably, a related issue that was frequently reported was finding the time to properly train new employees and struggling with employee accountability. This was particularly challenging for farms that employed teenagers and adults with physical disabilities and mental disabilities such as autism. The employment of disabled individuals was reported to present hurdles with personal protective equipment (PPE) compliance, overall training, and consistently performing food safety-related tasks. To address these challenges, some farms have attempted to develop a "culture of food safety" by further educating employees about the risks to consumers and making food safety the responsibility of every employee. However, this was not reported to be an easy task, and many growers expressed concern about the imple-

Table 3
Contextual themes

Themes	Illustrative Quotes
Worker Hygiene and Training	• "There is no hand washing inside the containers, so [the employees] hand wash when they go in. They wear gloves, and they're trained." • "The training is a challenge, just because our turnover of employees tends to be pretty frequent." • "PPE is a major issue. We insist that all of our employees, you know, wear masks and gloves as the Standard PPE uniform. We train and employ people with autism, and very frequently they cannot tolerate the PPE." • "[An employee is] not always going to want to be a stickler for the rules but getting that [food safety] culture to inoculate in your workplace, I think, is the biggest hurdle."
Agricultural Water	• "Well, the [water] testing process itself is outright cost prohibitive. It's upwards of a $100 a week, so when you're telling me that I have to budget $5000, to just do routine testing of my water sources, that's just not reasonable." • "And then the other thing was the water testing. How often do we do it? What are we looking for? Do we need to test the incoming water, and then also the water that's circulated in the system? Once we get the test, well, I don't know what we're actually looking for." • "We use a municipal water source, so it is a potable water source. We heavily inoculate it. You know, as we're an organic farm. We do a lot of beneficial microbial sort of releases into our water…We do not want to do any microbial testing because of false alerts… false positives [are] an insane headache." • "We have a filter battery; before the water comes into the facility [there are] spin down sediment filters, then activated carbon filters, and then UV filtration." • "In our in our tank, which is 110 gallons, we put 500 milliliters of ZeroTol® every other week, and a fungicide on the alternate week."
Soilless Substrates and Nutrients	• "You can get media, and store it, and you go to drag it into the facility and use it, and it's full of mold." • "We've used Oasis [Horticubes®] from the beginning… I would love to be able to use coconut coir in the little wraps, in the little cheese cloth stuff…but the problem with that is it's going to make the system dirty and might clog up the microtubes…monetarily, for us, [rockwool is] absolutely not worth it. It's triple the cost." • "So, we use a product, a peat product from a company called QuickPlug."
Pests and Biocontrol	• "[We use] a microbial package that is called TerraBella®… it's mostly for [preventing] biofilm development. We saw…mostly [that] it's…out-competing pathogens." • "Mice are the only thing that can get in. Battling with one right now actually, for the past three months. I can't catch him, I can't find him…" • "Really, the bugs are our only pest that we have to overcome or keep an eye on. I release about 500 lady bugs every few weeks in the farm, so they're always flying around and doing what they do. I think that helps." • "It's hundreds and hundreds of dollars a month, at least in a facility of our size, to have a commercial pest control program."
Harvesting, Storage, and Transportation	• "[Plastic clamshells are] not only expensive, but sometimes there's a lag in availability, and we would really prefer a sustainable green packaging option for all of our products. But unfortunately, very few manufacturers make those types of products." • "We currently use ZeroTol®, which we've been told by other growers is safe for hydroponic growing, but it does not have a sticker on it that says 'safe [for] food.'" • "I think temperature control has been our only real question mark." • "We had temperature monitoring where we could see the temperature. That was a big deal, because I was supplying [a large retailer] and [they require] fresh produce [have a] temperature inspection before they accept it.
Sanitizer Selection and Use	• "We basically use bleach on our surfaces. And then, if we have water that needs to be treated in any capacity we use hydrogen peroxide-based products." • "I've gone away from bleach, and I'm using food-grade, hydrogen peroxide…I have enough laboratory background that I try to keep things clean as possible. So, we work with some acids, and of course, the peroxide." • "We wipe all the tools with alcohol wipes…irrigation is cleaned out weekly, but it just flushes…no sanitization." • "And I think sanitizer selection is [challenging, including] proper use of individual sanitizers…directions, I think, can be challenging, too." • "We stay away from harsh chemicals, and we also have a cleaning crew that comes in at night to do the floors and tables, and I believe they use boiling water." • "We use ZeroTol® as our cleaning agent…we also use soap."

mentation of such a culture and the need for additional resources to support these efforts. Additionally, some growers reported difficulty retaining employees due to the high turnover rate in the agriculture industry, which further compounded their labor-related challenges.

Most of the produce growers obtained their agricultural water from wells or municipal sources. However, when it comes to water testing, many growers had a negative perception due to three primary reasons: (1) they did not understand the reason behind the testing, (2) the cost of testing was deemed too high, or (3) they feared false positives leading to a recall that could potentially ruin their reputation. Despite this, many produce growers still utilized some form of water filter, such as sediment, activated carbon, UV, and/or reverse osmosis, to mitigate waterborne contaminants. Some growers added hydrogen peroxide to their water supply for sanitization or pest control purposes. Additionally, many farms incorporated ZeroTol® into their practices to control plant pathogens (e.g., *botrytis*, powdery mildew, *Xanthomonas*, etc.), which was frequently added to their water supply (Hort Americas, 2023b).

Mold was identified as the primary issue with soilless substrates, as it could compromise product quality. However, most growers were unsure if moldy substrate posed a food safety risk to consumers. While Oasis Horticubes® emerged as the most commonly used soilless substrate, peat moss-based products were also popular. A handful of growers utilized rockwool, which was reportedly more expensive. Coco coir was suggested as a potential alternative to peat moss-based products, but concerns were raised about its potential to muddy the water and clog hydroponic systems.

Growers reported several issues with pests, and aphids (family: *Aphididae*) were identified as a common problem. Growers were concerned about the damage that aphids can cause to their plants, and many reported releasing adult ladybugs (family: *Coccinellidae*) as a common solution. Mice and other rodents were also viewed as occasionally problematic, and most farms reported using commercial extermination services to address this issue. While a few farms reported pests such as deer and raccoons at outdoor waste piles, they clarified that these waste piles were far from the indoor growing facility and posed no threat to their crops. Some organic farms reported using TerraBella®, a product that claims "the combination of aerobic and anaerobic microbes work throughout the root zone to increase crop yield and resistance to disease and pests" (Hort Americas, 2023a). However, one grower indicated their concern that this product may cause their water tests to come back positive for coliforms.

During the interviews, many growers expressed their concern about the cost and availability of disposable plastics, especially clamshells used in packaging. These growers were actively looking for more sustainable alternatives that would be both environmentally friendly and cost-effective. In addition to this, controlling climate factors such as temperature and humidity was identified as a significant challenge

Table 4
Barriers to risk management and regulatory compliance

Themes	Illustrative Quotes
Business Upgrades	• "I think I would definitely want to invest in a refrigerated van." • "I would minimize the hands touching the [produce]…and you know that takes a lot more automation compared to what we have, and to get that level of automation is a significant investment." • "The farm was designed with very little food safety knowledge put into the design, and I think that's one of the biggest lessons that we've learned from this facility, and… [that's] why we're building additional facilities." • "I would hire a firm to outsource or manage all the food safety aspects. Oh, and preventative sterilization or sanitation because my fear is it's hard to recover from recalls." • "[My biggest challenges are] around labor practices and inadequate infrastructure."
Regulatory and Certification Environment	• "One thing is there there's USDA and then there's FDA. It's like [the] food safety modernization act, and then there's USDA compliance stuff…and then you have all these different certification agencies or groups or protocols…I've done the USDA harmonized GAP, and [been] GAP certified for a number of years before. Now we're looking at like [SQF] and Primus [GFS]… but it's like you have all these different groups with some similarities, some differences, and then add on to it. Then the government where I'll get a letter from USDA, and I'll get a letter from [the state] and bills from both for a percentage of the audit or inspection. It just gets confusing…it's just like everyone wants a piece of the buy." • "I don't want to break the rules. I want to comply with the rules, but when it's a shock and blast of rules with 10 different groups, it gets confusing…are we making sure everything's right for the right people?" • "I know the USDA GAP is now the most rigorous audit you can do, so, I anticipate there being more rigor as we look to future audits."
Traceability	• "I know [traceability] was challenging to set up the first time. Now it feels pretty intuitive, but it's like, oh, potentially like a barrier to entry there. I think it does take a lot of organization, a lot of paperwork." • "I think, doing a mock recall is not the same as doing an actual recall. I haven't had to do [a real recall] yet. [I think that is] an area of concern for me." • "Perpetually, I am selling something to a restaurant that could have had a harvest date of 3 or 4 days in the past. And how am I supposed to put that on a label? And how granular do I need to get with that documentation?" • "We follow tracking with the barcode system and the software. We have the cameras that can monitor all this traceability information. We are in pretty good shape in terms of meeting the traceability, but the dynamics, how the documentation has to be done, and what kind of traceability, quickness that is needed, that we still have some work to do on that."

in the industry. Maintaining the cold chain during the transportation and storage of produce was also identified as occasionally problematic by growers. Specifically, temperature fluctuations during distribution could have a significant impact on the quality and shelf life of the produce, potentially causing their entire shipment to be rejected by the buyer. To address these challenges, growers discussed implementing advanced monitoring systems to keep track of environmental conditions. Some growers also explored alternative packaging materials, such as biodegradable plastics or reusable containers, to reduce waste and costs while maintaining product quality. Overall, growers were keen to find innovative solutions to these challenges to ensure the long-term sustainability and profitability of their operations.

Table 5
Research needs

Themes	Illustrative Quotes
Algae Control	• "Algae is always one that that we can't overcome, and I think everyone has that problem. So that's definitely an area of research that we need to figure out." • "The only thing that's a challenge for us in particular is the algae." • "We can't eradicate the algae. I don't think that's possible, but we do have various steps to keep it under control."
Postharvest Storage, Treatment, and Washing	• "Any kind of information on ideal post-harvest procedures to maximize shelf life and mitigate your risks. [It would] be nice to have more robust best practices." • "Research that would be beneficial is, what can you do [with] a non-aqueous sanitizing step [for produce] that would actually increase shelf life." • "It would be good to have more information about the harvesting [and storage]."
Risk Assessments of Individual Issues	• "I want more than somebody to just say, yeah, they're fine. I want to see data, and I don't think that data has been out in front of a lot of things that it should have been, and like I said before, everybody rushes in this industry to be the biggest, the fastest, the best…that big chase, that big race, has left that important information behind, and I think there needs to be a real concerted effort to get that out there…It's a little bit more serious than the industry seems to be taking it… I've been watching, you know, recalls and all of that stuff my whole career, and the last 6 to 9 months, it just feels like the flood gates have opened up…But then it's like you want to know how each factor is influencing that system and that can be challenging." • "[How do I know if] this is a real safety risk? What should I do [if it is]?" • "People don't get a lot of chances…like failing food safety, and then learning from it. You need to do it right from the start, and what we don't have practice in is what type of issues [are important] in a food safety risk situation? • "People who have recalls and pathogen outbreaks…What did they do wrong to get there? We don't know, because we haven't been through it. You should be able to learn from other people's mistakes."
Training Program Development	• "Well, as far as we're concerned, there's a lack of a turnkey concise gold standard that we can check off boxes and run through with staff of all different backgrounds. So, to not have that in a concise, quick format it is a challenge. So, we're kind of left to our own devices to establish it within our own specific space and make it as abbreviated as we can, because frankly, it's not a complex environment, and you're going to run the risk of the employee not retaining it, not following it if it's cumbersome because food safety practices are not a one size fits all approach depending on the operation." • "I mean, I've seen that there's lots of these grower training seminars and all that stuff. I just wish there was free ones, you know. It seems a little bit crazy that they're starting at like $450 or something like that."

Sanitizer selection was a major concern for many growers due to the varied options available in the market. While some growers were comfortable using bleach, many were hesitant to use it because of the potential harmful effects on the environment and worker safety. As a result, they turned to alternative sanitizers such as ZeroTol®, soap, boiling water, peroxide, various acids, and alcohol wipes. However, there was no consensus on which sanitizer was the best for a particular operation, and some growers even admitted to not cleaning or sanitizing certain equipment such as water-recirculating pumps or hydroponic tanks. The confusion around sanitizer selection was compounded by the fact that different sanitizers had different directions for use, and growers were not always clear on how to properly use them. Many growers were concerned about using "harsh" chemicals that might harm their workers or the environment, so they were hesitant to try new sanitizers. This was particularly true for organic farmers who wanted to avoid synthetic chemicals altogether. Some growers were open to trying new sanitizers, but they were unsure of how to evaluate them and what factors to consider when selecting a sanitizer product.

Barriers to Risk Management and Regulatory Compliance. In terms of business upgrades, growers sought a variety of improvements to enhance their operations. If financial resources were available, one of the most common upgrades was to acquire equipment to improve cold chain maintenance, such as refrigerated vehicles or additional refrigeration space. Many growers also expressed interest in automation to help monitor climate factors, with some seeking upgrades for every step of the growing, harvesting, and packaging process. Aspects of automation that growers were interested in varied greatly, but many expressed the desire for software or technology to help with tasks such as tracking inventory, managing crops, and monitoring employees to ensure adherence to required protocols. Another common request was for someone to manage the various administrative tasks and food safety monitoring required of their operations. Many growers were overwhelmed by the amount of paperwork and bureaucracy involved in running a successful leafy greens operation and felt that having a dedicated person or team to handle these tasks would be a valuable asset. In addition to upgrades to equipment and administrative tasks, some growers expressed interest in expanding their growing space or providing additional training resources for their employees. With a growing demand for locally sourced produce, many growers saw potential for expanding their operations and increasing their yield but felt that they needed more space or training to do so effectively.

Growers frequently expressed uncertainty about the regulatory requirements for their operations. They indicated that it would be ideal to have a clear understanding of the recommended best practices and legal requirements. They often felt overwhelmed by the number of possible certifications available from various agencies and organizations. Perceived differences between USDA and FDA requirements and conflicts with local state agencies and inspectors added to their confusion. Many growers also expressed frustration with the lack of consistency in regulatory requirements and inspections, leading to confusion and uncertainty. Despite these challenges, all growers shared a desire for compliance, indicating their willingness to adhere to regulatory standards whether or not covered by the PSR. However, the lack of clear and concise information was a common obstacle in achieving this goal. Some growers also mentioned the need for a streamlined certification process that is both affordable and applicable to their specific operations. They suggested that regulatory agencies work more closely with growers to understand their unique needs and provide guidance on achieving compliance. The study participants emphasized that regulatory compliance is not only important for consumer safety but also for the success and reputation of their businesses.

In the area of traceability, many growers expressed a desire to improve their systems. Some growers mentioned that they had a learning curve when it came to traceability, but that it became easier with time. Most growers had some sort of system in place, such as digital barcoding or spreadsheets, to track specific produce lots. However, there was some variation in the level of sophistication of the traceability systems between different growers. Some growers were not convinced of the value of mock recalls, which are required by certain certifications. They felt that a real recall would be significantly different and were unsure of how to prepare for it. The biggest challenge for many growers was determining how granular their traceability systems needed to be, and what was required versus what was recommended.

Research Needs. The issue of managing algae growth was a common theme among the growers. They expressed a strong need for implementing standardized methods to control algae growth, which was found to be a significant challenge for many of them. Algae is a concern because it may clog the tubes within their hydroponic systems, leading to reduced efficiency and increased expenses. Additionally, the study participants expressed concern that the growth of algae may also deplete the valuable nutrients within their nutrient solutions, which could further impact crop yields. Many of the growers had already attempted various methods to control algae growth, such as manual removal or the use of chemical treatments. However, they indicated that these methods were often time-consuming, ineffective, or had undesirable side effects. Some growers expressed interest in exploring alternative methods, such as the use of beneficial microorganisms or the implementation of microbicidal light treatment systems such as ultraviolet-C radiation.

A significant number of growers indicated their interest in postharvest treatments as a means of improving the shelf life of their leafy greens. Specifically, the growers mentioned the importance of implementing washing, nonaqueous and aqueous produce sanitization methods, and better storage conditions to prolong the shelf life of their produce. It was clear from their responses that they were mainly interested in these practices for their potential impact on profitability, rather than food safety concerns. The growers understood that by increasing the shelf life of their products, they would be able to reduce waste and potentially increase their profits. Despite the fact that food safety may not have been the primary motivation behind these postharvest treatments, it is worth noting that they could still have a positive impact on reducing the risk of contamination and improving the overall quality of the produce.

The growers in the study expressed a strong desire for science-based risk assessments of individual issues within the industry, as opposed to receiving generalized advice. They felt that having access to data would enable them to make informed decisions about the risks they face and how to manage them effectively. However, many growers were concerned that the industry was moving too quickly without proper consideration of the potential risks involved. As a result, they wanted to understand which factors were important for food safety in order to avoid making mistakes that could lead to pathogen outbreaks or recalls. The growers suggested that there needs to be a concerted effort to gather and disseminate this information to prevent future problems. Overall, the growers emphasized the importance of proactive measures to address food safety issues and a desire to learn from past mistakes in order to avoid future ones. Specifically, many growers expressed a desire to learn from other growers' mistakes. They suggested that information about the causes of past recalls and pathogen outbreaks should be publicly available and easily accessible. By understanding what factors contributed to these incidents, growers could take steps to avoid similar situations and improve their own food safety practices. However, at present, there appears to be a lack of transparency and communication about the causes of food safety incidents in the industry. By making information about past incidents more readily available, the industry could facilitate a more collaborative and proactive approach to food safety. Growers could learn from each other's experiences, and the industry as a whole could work to identify and address common risk factors. This could help to prevent future incidents and ensure the safety of the food supply for consumers.

Growers unanimously expressed a strong need for concise, standardized training programs to ensure that their staff understands and follows best practices for food safety. The growers acknowledged that food safety practices cannot be applied in a "one size fits all" approach, but they emphasized that the lack of a standardized program can be challenging. The growers want a turnkey, concise, and standardized gold standard that can be easily implemented for staff with varying backgrounds. They also highlighted that free training programs would be beneficial in ensuring that all growers, including smaller ones, have access to the information they need to maintain food safety standards. Many of the growers noted that the existing training programs can come at a high cost, which can be prohibitive for them and their employees.

Discussion

This study aimed to identify barriers to implementing risk management practices and industry challenges within indoor, soilless leafy greens production through analysis of semi-structured interview transcripts. This approach enabled valuable insights into the practices adopted by growers and identified potential gaps in knowledge and practices that could lead to food safety concerns for the produce industry and consumers alike. The three major themes were contextual, barriers to risk management and regulatory compliance, and research needs. These themes guide the discussion of this study.

An investigation on growers' food safety perspectives conducted by Parker and colleagues (2012) identified two risk factors that have a considerable impact, namely the potential loss and uncertainty. The researchers found that these risk factors were significantly associated with the scale of the farm and the method of marketing, referring to how growers sell their produce. In the present study, similar results were obtained from interviews with leafy greens growers, revealing that the larger growers who supply chain grocery stores or institutional foodservice providers are more likely to have mandatory employee training and frequent inspections and/or audits from both state and government agencies. In contrast, smaller growers selling their products at local farmers' markets or food cooperatives may have less training and may not participate in third-party audits or other types of on-farm inspections related to the implementation of the PSR.

Although several needs assessments have been carried out to determine the requirements of produce growing operations, the specific needs of indoor, soilless leafy greens growers have not been extensively studied. Chen et al. (2021) reported that agricultural water and soil amendments were sources of uncertainty for produce growers, which is consistent with the confusion reported by leafy greens growers in the present study regarding water testing. However, since soil is not typically used in CEA systems, soil amendments are not relevant in this context. Perry et al. (2019) found that the least understood topics for produce growers in the Midwest included agricultural water requirements, protection of crops from animal fecal contamination, and worker training. These findings are partially in-line with the current assessment of indoor leafy greens growers, which identified worker hygiene and training, agricultural water, training program development, and soilless substrates and nutrients as subthemes. Since CEA operations are indoors, protecting crops from animal feces is less of a concern (i.e., rodents were the only reported mammalian pest, and no avian pests were reported).

The majority of growers reported varying degrees of challenges with employee adherence to food safety guidelines. Reasons for this included limited training, lack of employee awareness regarding the significance of specific rules, constraints on time (i.e., to provide training), as well as mental or physical disabilities. Specific to the latter point, Hedley and co-authors (2017) assembled a focus group of adults with autism spectrum disorder and had them participate in a 3-year employment and training program. Sub-thematic enablers (factors found to be related to successful employment outcomes) were organization support, advice from co-workers, supportive leadership, allowance of environmental modifications, and the presence of a consultant. Sub-thematic challenges (factors found to be related to unsuccessful employment outcomes) included task-related difficulties, individual factors, social difficulties and distractibility, not managing work-related stress, and being perceived to be too frank (Hedley et al., 2017). Regardless of employee status as neurotypical or neurodiverse, more effective training programs to meet the needs of the rapidly growing CEA industry are warranted and would be useful to all operations no matter their social mission (e.g., providing meaningful employment to marginalized populations).

Produce can be exposed to microbial contaminants through agricultural water, which is recognized as a primary route of contamination (FDA, 2015). However, most produce operations surveyed in the current study (n = 8; 72.7%) could be exempt from the PSR due to having 1) food sales less than $25 000 (averaged over the previous three years) or 2) the majority of all food sales (with annual revenue less than $500 000) to qualified end-users (FDA, 2015). From the interviews, it was evident that several produce growers who performed water testing were not examining the water for pathogens but rather for nutrients or other water quality parameters such as pH and electrical conductivity. This suggests a lack of understanding among certain growers regarding the principles of water testing from a microbial food safety perspective. Growers were clearly concerned about water quality as they took measures such as digging wells deeper, applying a filtration step, and adding chemicals such as ZeroTol® and hydrogen peroxide.

The primary concern expressed by growers regarding soilless substrates was the emergence of mold. This is a significant issue, as mold growth is linked to high humidity levels of 60–75% and frequently leads to crop damage and losses (Jones et al., 2021). Related to nuisance organisms, aphids were most growers' biggest complaint. While all complainants expressed aphids causing issues with produce quality and growth, none expressed concern about pathogen transmission. Aphids are known to transmit plant pathogens, and it is not unreasonable to suspect they could also transmit human pathogens throughout a facility (van Munster, 2020).

Some growers struggled with controlling climatic factors, such as temperature and humidity, especially when transporting produce to buyers. Many growers indicated that buyers (specifically chain grocery stores) would test the temperature of their produce upon arrival before accepting it. This practice does not guarantee that produce has not been temperature abused, as it could have easily been at temperatures above acceptable parameters, and then re-cooled to acceptable temperatures. Zi and coauthors (2021) found that cost sharing (i.e., in cold chain equipment and marketing and advertising) may help boost demand and enhance the profits of members of the supply chain, and that bilateral cost sharing is found to have a more significant impact than unilateral cost sharing. No such cost sharing was mentioned by any growers in this present study. Moreover, many growers used plastic clamshells to package their produce. This type of container is likely not conducive to maintaining the cold chain, as vented clamshells are made of thin plastic and designed with many holes in order to reduce moisture accumulation. An area of improvement may be to incorporate energy-efficient packaging options (Defraeye et al., 2015).

Growers had mixed opinions about the use of sanitizers, with some preferring to use bleach, while others found bleach to be too "harsh" or "unsafe for workers." The use of hydrogen peroxide, ZeroTol®, alcohol wipes, or simple soap and hot water were alternatives used by those opposed to bleach. This suggests that there was a general lack of understanding of food safety concepts among some growers, including the distinction between cleaning and sanitizing. This same misunderstanding was observed by Hamilton et al. (2023) in their study of microgreens growers. The U.S. Environmental Protection Agency (EPA) in the U.S. regulates all antimicrobial products, including chemical sanitizers. According to the EPA, sanitizers are substances or mixtures that significantly reduce bacterial populations (e.g., by 10^3) in the inanimate environment, but do not eliminate all bacteria.

In the current study, growers frequently reported the use of food-grade hydrogen peroxide throughout their leafy greens cultivation process, from hydroponic tank water to cleaning harvesting tools and surfaces. Hydrogen peroxide (H_2O_2) is an oxidizing agent that is employed by some organic farms for disinfecting recirculated irrigation water in hydroponic systems (Eicher-Sodo et al., 2019). Although H_2O_2 generates the hydroxide ion, which can control microorganisms to some extent, its application has mostly been explored in the context of algae, insect pests, and plant pathogens (Baldry, 1983; Bosmans et al., 2016; Raudales et al., 2014; Vänninen & Koskula, 1998). These studies have been previously summarized by Hamilton and colleagues (2023). In brief, there is limited evidence regarding the efficacy of H_2O_2 for the control of microorganisms, including pathogens, on both food-contact and non–food-contact surfaces.

Coosemans (1995) provided a comprehensive summary of the issues associated with algae control in hydroponic systems, stating that algae not only cause obstruction problems but also pose a threat to crop nutrition and lead to unpleasant odors and appearance. Similarly, Schwarz and Gross (2004) observed a negative impact of algae on hydroponic crops. Caixeta et al. (2018) evaluated the efficacy of various agents, including H_2O_2, against algae, shore flies, and fungus gnats. While H_2O_2 had an adverse impact on lettuce seed germination, it significantly reduced algae growth over the 15-day experimental period. In contrast, aqueous ozone was proposed as a promising alternative to H_2O_2 as it demonstrated significant reductions in algae growth without causing any phytotoxicity in tomato plants (Graham et al., 2011). Graham et al. (2011) also observed a significant increase in leaf area, shoot dry matter, and stem thickness in tomato plants exposed to aqueous ozone via the hydroponic nutrient solution at the highest treatment level (3.0 mg/L). Riggio et al. (2019) previously summarized water treatment options available for recirculating hydroponic systems including their respective limitations.

There is a growing interest in postharvest treatment research aimed at improving the shelf life and safety of produce. However, there is a debate among growers on whether produce should be washed and how it should be stored. While washing with tap water has been shown to reduce pathogens on fresh produce, it may also lead to cross-contamination during washing and thus contaminate previously uncontaminated produce (Jensen et al., 2015). In fact, an expert panel on the microbial safety of fresh produce advised against washing fresh produce due to the risk of cross-contamination during washing, which may outweigh any safety benefit that further washing may confer (Palumbo et al., 2007). Despite this recommendation being primarily for consumers and retail foodservice operators, growers in the present study generally did not wash their leafy greens before sale due to the perception that produce grown indoors is "cleaner" and to extend product shelf life by not introducing moisture.

The availability of free training programs for employees was identified as a concern among many growers. While acknowledging this concern, it is worth noting that training programs do exist, and at a relatively low cost. For example, ZipGrow, Inc,—an agriculture technology company that has developed a variety of hydroponic growing systems—offers training programs including the UpStart University at a rate of less than USD $10 per month, which could be highly beneficial for growers looking to upskill their employees (ZipGrow, Inc. 2023). However, these general educational platforms aimed at hydroponic and aquaponic growers may not meet all the needs of a given operation. It is worth noting that other industries, such as the food service industry, often require their workers to obtain specific training, such as ServSafe® training (ServSafe, 2023), which varies in cost depending on the course and delivery mode. In an ideal world, comprehensive training or guidance materials would be developed to clarify the regulatory expectations for growers across different states, thus alleviating any confusion or concerns that growers may have. Such materials could help to demystify regulatory requirements and ensure that growers are equipped with the necessary knowledge and skills to meet these requirements.

This study aimed to examine the needs of indoor, soilless leafy greens growers and explore the challenges they face in implementation of food safety risk management practices. The use of semi-structured interviews paired with a demographic/operational survey as the study methodology has several strengths along with a few limitations—some common strengths and limitations related to interviews have been outlined previously by Knott et al. (2022). First, we have a limited sample size ($n = 25$) with a somewhat restricted geographical distribution (i.e., 22 out of 47 states with identified CEA operations). These 25 growers represent approximately 14% of the operations that were successfully contacted. However, sample sizes of 20–40 are common for interview-based qualitative research, often reaching thematic saturation after about the 9th to 17th interview (Hennink & Kaiser, 2022). In addition, less than half of the interview participants completed the accompanying survey, thus a complete characterization of operation type and size of CEA operations participating in the interviews was not possible. Regardless of the perceived sample size limitations, the interviews provided a richness of data that could only be gathered using the semi-structured interview approach (Knott et al., 2022). This collection of in-depth insights allowed the authors to identify potential action items and future research directions to aid in the advancement of food safety within the CEA leafy greens industry.

Based on the overall findings, the authors recommend the establishment of a centralized source of information that provides growers with specific regulatory requirements for their geographic area, as well as recommended growing practices, business operation practices, and food safety information. This centralized source of information could help to alleviate some of the challenges identified in this study and facilitate the development of customized training for growers. More broadly, the results of this study provide insight into the challenges facing growers in CEA and highlight the need for additional grower education and training. Furthermore, this research seeks to contribute to the field of food safety and inform the development of educational resources to protect the safety and wholesomeness of the U.S. food supply. To build on these findings, it is recommended that this study be repeated after the establishment of the centralized information source and other grower education resources. Additionally, observational studies at indoor, soilless leafy greens growing facilities and testing of facilities for common indicator microorganisms and foodborne pathogens would be useful in furthering our understanding of the food safety risks associated with CEA.

CRediT authorship contribution statement

Zeynal Topalcengiz: Methodology, Investigation, Writing – review & editing. **Kristen E. Gibson:** Conceptualization, Methodology, Investigation, Data curation, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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