



Assessing Food Safety Needs and Agricultural Water Quality Among Alabama Specialty Crop Growers: A Two-Phase Study

ABSTRACT

Alabama has over 2,000 farms that grow produce, yet limited data exists on food safety needs. To address this, a two-phase study was conducted. Phase 1 consisted of a 15-question needs-assessment survey (Qualtrics, n=99) targeting specialty crop growers. Based on identified priorities and historical concerns about water quality in Alabama, Phase 2 involved the development of the *AgWater Safety Program*. The program provided free microbial water testing. Participants (n=20) completed a 10-question survey to determine eligibility. Water samples were enumerated for generic *Escherichia coli*. In Phase 1, respondents had received Produce Safety Rule training (49%) and GAP training (42%). Top training interests included food safety plan writing, cleaning and sanitizing, and postharvest handling. In Phase 2, 83 water samples were collected. Generic *E. coli* was enumerated in different water sources, including surface (20/34), groundwater (2/33), and municipal (0/9). Many participants (60%) had never tested their water before the program. Although Phase 2 enrollment was limited (n=20), the results still

provide critical insight into grower practices and water quality trends that directly inform future food safety programming in Alabama. This information will guide Alabama food safety educators in establishing produce safety programming, prioritizing the current needs.

INTRODUCTION

The consumption of contaminated fresh produce is a well-known contributor to foodborne diseases globally (8, 10, 36). Fresh produce is commonly subject to multiple contamination routes, including contaminated water, humans, animal intrusion, and poorly designed facilities (2, 3, 31). In the United States, foodborne illnesses significantly impact public health and business, with fresh produce accounting for 46% of these cases (25). Additionally, the Centers for Disease Control and Prevention (CDC) reports that leafy greens have been identified as a significant source of foodborne outbreaks in recent years (11). Despite the implementation of food safety regulations and industry standards such as the Produce Safety Rule (PSR), Leafy Greens Marketing Agreement (LGMA), and Good

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Agricultural Practices (GAPs), foodborne outbreaks associated with fresh produce continue to be a significant cause of illness (5, 12). Current produce safety regulations, certifications, and standards primarily focus on medium to large operations, while small and very small growers are generally subject to less stringent oversight (6). However, despite their smaller scale and more localized distribution through grocery stores, farmers' markets, and u-pick operations, these smaller operations can still be responsible for foodborne illnesses (14).

Various food safety assessments conducted nationwide have consistently highlighted the key challenges growers face in implementing food safety standards. These challenges primarily include a lack of time, financial resources, and access to necessary training and information. Additionally, smaller operations often struggle with the complexity of compliance requirements, further exacerbating these difficulties (13, 17, 25, 28). Investigations from previous outbreaks have elucidated the importance of food safety education, employee training, and overall behavioral change as a key to preventing produce contamination at the farm level (12). Although only a limited number of foodborne outbreaks have been linked to fresh produce sold at farmers' markets, such as peas and strawberries (18, 19), research has shown the presence of foodborne pathogens (e.g., *Campylobacter jejuni*, *Listeria monocytogenes*, pathogenic *Escherichia coli*) in various horticultural commodities from small growers, including leafy greens, radishes, and green onions (6, 27, 30, 34).

Alabama has over 200 farmers' markets, and most growers receive food and water safety education from trade associations or extension educators from Land Grant Universities. However, limited studies have assessed Alabama's specific food and water safety needs (14, 16, 20). The most recent U.S. Census of Agriculture (2022) estimates that most produce growers in Alabama are very small operations, with many being family-owned or individually operated (38). The Census also reports that in 2022, Alabama had at least 1,400 farms harvesting vegetables for sale and over 1,700 farms with fruit orchards. Among these, at least 2,000 farms use irrigation for their horticultural commodities (38). Although most of the U.S. has access to an on-site sanitation system, several counties in the Black Belt (BB) region of Alabama lack access to sanitation systems, increasing the risk of water contamination (41). Various produce operations are located within the BB, which is characteristic of having alkaline, dark, clayey soil that prevents water infiltration, elevating the risk of runoffs and potentially leading to contamination of water sources (24). Additionally, several houses in the BB area still use the "straight pipe system," which has been linked to increased levels of fecal bacteria and pathogen discharge into the environment (9, 24, 35).

While most of the research and outreach efforts in the state have focused on drinking water with programs or

for recreational water use, none of the programs focus on microbial water quality for agricultural purposes. An exploratory study was conducted to identify produce safety needs and better serve Alabama's produce growers, utilizing a needs assessment survey as the primary tool. Based on Phase 1 survey findings, targeting the specific knowledge gaps, training priorities, and preferred learning formats identified by Alabama produce growers, a second phase was focused on developing an educational program and providing a free water sampling service specifically for agricultural water used by Alabama growers.

MATERIALS AND METHODS

Research approach and survey design

A two-phase study was developed to identify and address the food safety needs of fresh produce growers in Alabama. Phase 1 involved developing and administering a needs assessment survey (*Supplemental Material 1*), while Phase 2 focused on implementing an extension program to support safe agricultural practices focused on water.

Phase 1: Needs-assessment survey

A needs-assessment survey was developed and administered using Qualtrics (Qualtrics, Provo, UT). The survey was approved for use with human subjects by the Auburn University Institutional Review Board (Protocol #21-192 EX 2104). It consisted of 15 primarily multiple-choice questions covering demographics, farm characteristics, training in food safety, communication, and training preferences. Demographic questions included language spoken, farming experience, role on the farm, and education level. Questions about farm characteristics addressed business size based on annual sales, commodities grown or handled, types of farm activities, location of the farm or packing operation, and compliance with the PSR. The food safety training section explored participants' prior training experiences and topics of interest for future training (both for growers/management and employees). In addition, the survey collected information on communication and training preferences, which included the sources of food safety information and preferred training format. To facilitate completion, the survey used primarily multiple-choice questions.

Phase 2: Development and implementation of the AgWater Safety Program

Based on Phase 1 results, a second survey (*Supplemental Material 2*) was developed to assess the eligibility of participation in an extension program focused on the safety of agricultural water used in fresh produce production. This survey was also administered via Qualtrics and approved by the Auburn University Institutional Review Board (Protocol #21-192 EX 2104). The 10-question survey gathered information about farm characteristics, crop production, marketing channels, and water use and safety

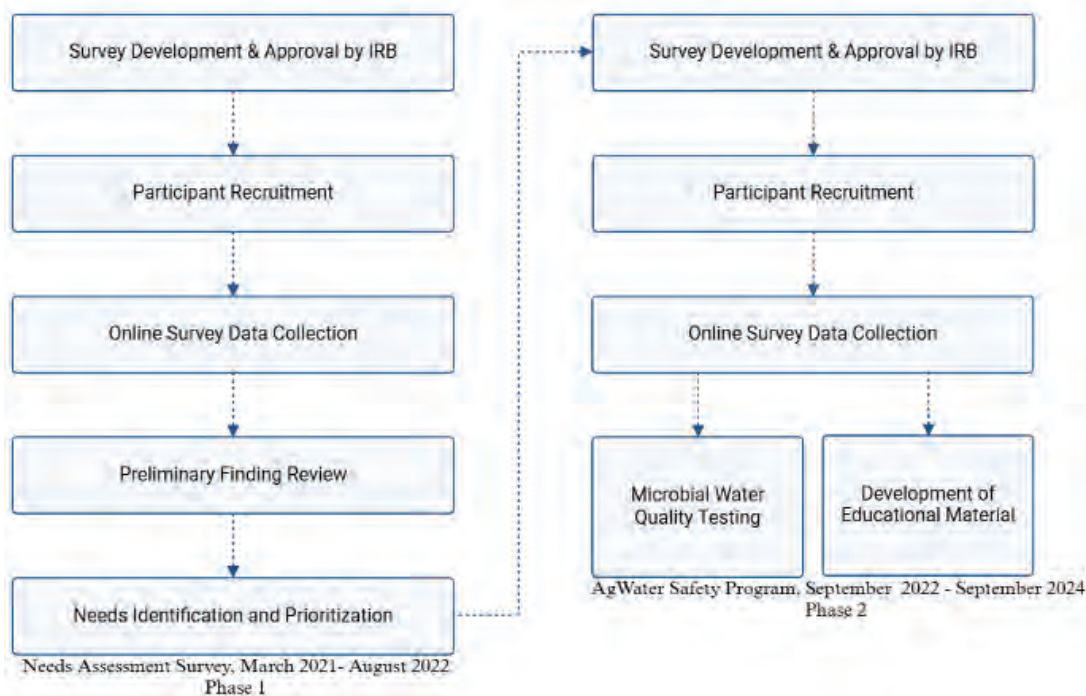


Figure 1. Workflow of the two-phase study on food safety needs and agricultural water practices in Alabama by produce growers.

practices. Questions on farm characteristics included farming experience, business size based on annual sales, crop types, and animal presence on the farm. Participants were asked about marketing channels, such as whether products were sold to local schools, farmers' markets, or wholesale buyers. Water use and safety questions were explored, the types and number of water sources were discussed, and whether water testing had been conducted. Participants were asked to identify their farming operations' location(s) to provide geographic context for the responses.

Participant recruitment and survey distribution

To be eligible to participate in the needs assessment, respondents were required to be at least 19 years old and identify as a fresh produce grower, harvester, packer, sheller, food safety supervisor, or other member involved in fresh produce production. The needs assessment survey was distributed from March 2021 to August 2022. This survey targeted specialty crop growers in Alabama, as well as personnel involved in tasks related to produce on the farm (e.g., packers, crew members, food safety managers). The survey was distributed broadly through social media platforms, listserv emails, and outreach during workshops and training sessions. For the *AgWater Safety Program*, which recruited participants from August 2022 to August 2024, the eligibility criteria consisted of individuals who were at least 19 years old and actively engaged in fresh produce production. Recruitment for this phase was conducted

through direct outreach, produce safety training, field days, farmers' markets, and targeted email. Extension agents and personnel from the Horticulture Department at Auburn University supported participants' recruitment. Both surveys were available using the provided link or a QR code. Only complete surveys (100% responses) were considered for the descriptive analyses. A visual summary of the study workflow is provided in *Figure 1*.

Sample testing methodology

After completing the *AgWater Safety Program* survey, qualified individuals received a sampling kit containing sterile polypropylene bottles (Nalgene, Rochester, New York, U.S.), alcohol wipes, hand sanitizer, disposable sterile gloves, reusable ice packs, sampling instructions, and a prepaid shipping label (*Supplemental 3*). After collecting the water samples, participants shipped the cooler overnight to Auburn University for microbial analysis within 24 hours. The samples were accompanied by a submission form specific to the laboratory to provide information on water sources, including the type of water sources and the date and time of sample collection (*Supplemental 4*).

The IDEXX Colilert Test with Quanti-Tray/2000 (IDEXX Laboratories, Westbrook, ME) was used to enumerate generic *E. coli* and coliforms, with results recorded as Most Probable Number (MPN)/100 mL. Following the manufacturer's instructions, water samples were added to 100-mL containers containing sodium thiosulfate, vigorously

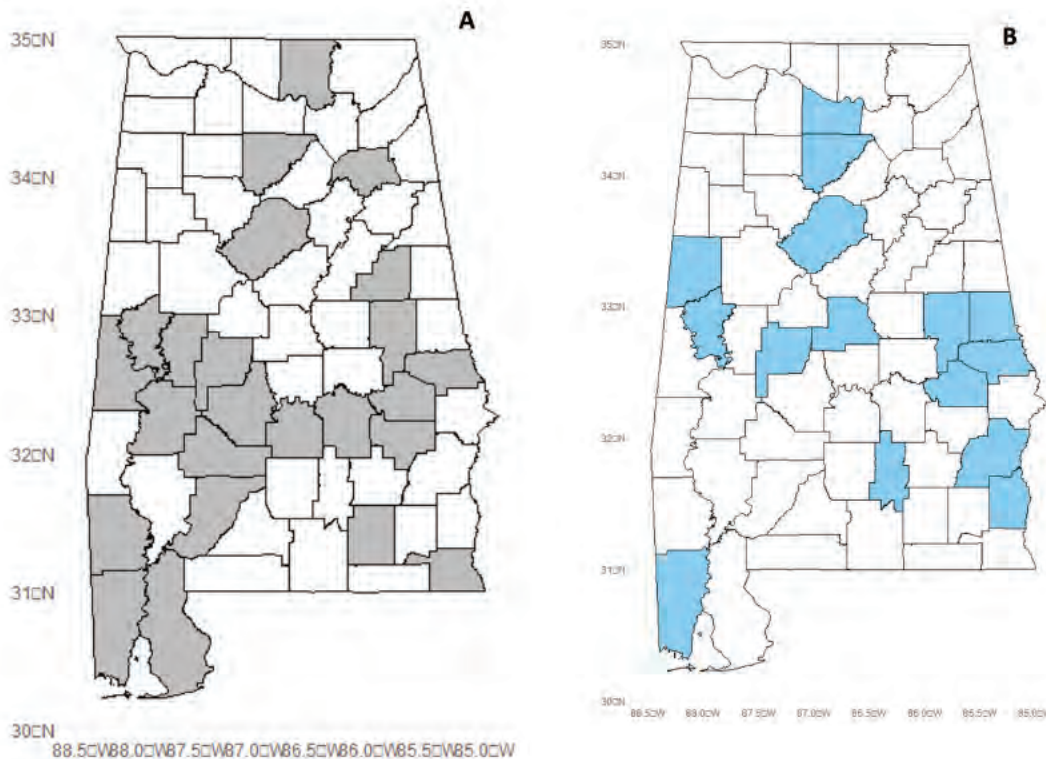


Figure 2. County representation and response to needs-assessment survey (A) and AgWater Safety Program (B).

shaken to dissolve the reagent, then sealed in a Quanti-Tray and incubated at $35^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$ for 24 hours. The MPN for generic *E. coli* and total coliforms was determined based on the number of large and small wells that fluoresced under ultraviolet light and turned yellow for coliforms, as previously described (22). MPN values were calculated using a table provided by the manufacturer. The detection range was <1.0 MPN/100 mL (lower limit) to $>2,419.6$ MPN/100 mL (upper limit).

Data analysis

All data cleaning, visualization, and analyses were conducted in R Statistical Software (version 4.3.0, 2023-04-21 ucrt). Descriptive statistics were used to summarize participant demographics and survey responses. A principal component analysis (PCA) was utilized to identify potential interrelations among variables in the needs assessment dataset.

RESULTS

Needs-assessment survey

A total of 99 survey respondents were included in the descriptive analysis, representing 25 counties across Alabama. Most responses originated from Central and South Alabama (Fig. 2-A).

Demographics

Table 1 summarizes participants' demographics. Most respondents were farm owners (33.7%), followed by managers (24.3%), field crew members (14.3%), food safety managers (9.3%), transport workers (5.6%), sanitation crew members (3.7%), and food safety assistants (3.1%). Additionally, 3.7% held clerical or miscellaneous roles, including consultants, helpers, or group directors. Nineteen percent of owners reported holding multiple on-farm roles; one food safety assistant also served as an educator. Regarding farming experience, 10.1% of participants planned to begin farming, while 30.3% had between 1 and 10 years of experience, and 19.2% had more than 10 years of experience. However, 40% of respondents did not report their experience level. English was the primary language spoken on most farms (74.74%), followed by Spanish (6.06%).

Farm characteristics and horticultural commodities

Participants reported their business size based on annual gross produce sales. Thirty-five percent fell into the "very small business" ($< \$28,000$ annually), 11% were classified as "small businesses" ($\$28,000$ – $\$500,000$ annually), and 3% were "large businesses" ($> \$500,000$ annually). The remaining 50% chose not to disclose their business size. As detailed in Table 2, the most common on-farm activities included

TABLE 1. Participant Demographics - Needs-assessment Survey (n = 99)

Demographic characteristics	Survey participant % (n)
Education Level	
More than 4 years of college	6.06 (6)
4 years of college	7.07 (7)
High school/GED	5.05 (5)
Not specified	81.81 (81)
Role Overall	
Owner	33.75 (54)
Manager	24.38 (39)
Field crew	14.38 (23)
Food safety manager	9.38 (15)
Transport	5.63 (9)
Sanitation crew	3.75 (6)
Other	3.75 (6)
Food safety assistant	3.13 (5)
Clerical staff	1.88 (3)
Single Role	
Owner	35.35 (35)
Manager	17.17 (17)
Food safety manager	5.05 (5)
Food safety assistant	1.01 (1)
Field crew	12.12 (12)
Transport	1.01 (1)
Multiple roles	20.20 (20)
Farming Experience	
Planning to farm	10.10 (10)
1–10 years	30.30 (30)
More than 10 years	19.19 (19)
Not specified	40.40 (40)
Language	
English	74.74 (74)
Spanish	6.06 (6)
Not specified	19.19 (19)

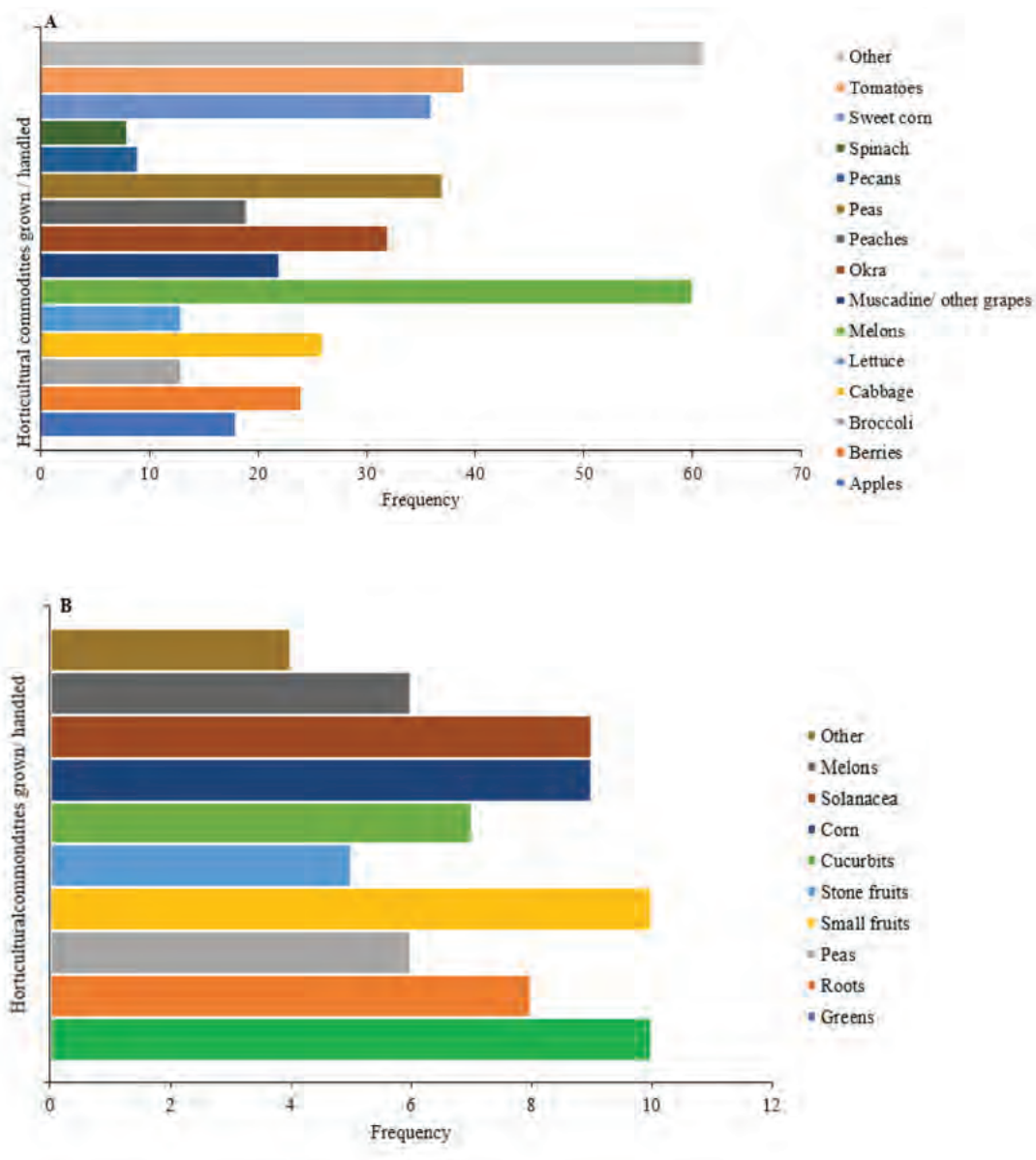


Figure 3. Frequency of horticultural commodities reported by Alabama Farms: Needs-assessment Survey (A) and AgWater Safety Program (B).

outdoor growing (85%), controlled environment agriculture practices (35%)—like greenhouse, vertical or indoor growing activities—rinsing (45%) and packing (43%), and the management of storage in coolers (31%). Additionally, 34% reported engaging in further processing such as cutting, cooking, and canning (34%) and transporting horticultural commodities (3%).

Horticultural commodities grown by the respondents included solanaceous, brassicas, leafy greens, and berries (Fig. 3-A). Most respondents reported growing various horticultural commodities simultaneously, while others responded growing commodities not listed in our survey,

including sweet potatoes, cucurbits, citrus, onions, and sugar cane. Among respondents, 53% were unsure whether their farm was required to comply with PSR, 26% reported they were not required to comply, and 20% indicated compliance (Table 2).

Food safety training-related topics

Participants were also asked about prior food safety training (Fig. 4). Nearly half (49.5%) of individuals reported completing the Produce Safety Alliance (PSA) Grower Training, while 42% had received Good Agricultural Practices (GAP) training. Additional training included

TABLE 2. Farm characteristics of participants–Needs-assessment Survey (n = 99)

Farm characteristics	Survey participant % (n)
Business size	
I prefer not to answer	50.50 (50)
Very small business (<\$28K in produce sales annually)	35.35 (35)
Small business (\$28K - \$500K in produce sales annually)	11.11 (11)
Large business (> \$500K in produce sales annually)	3.03 (3)
Farm activities*	
Outdoor growing	85.85 (85)
Harvesting	72.72 (72)
Holding/Cooler storage	45.45 (45)
Rinse	44.44 (44)
Wash	43.43 (43)
Greenhouse growing	35.35 (35)
Packing	35.35 (35)
Transportation	34.34 (34)
Processing (cutting/cooking/canning/etc.)	31.31 (31)
Other (packing house)	3.30 (3)
Compliance with Produce Safety Rule (PSR)	
Not sure	53.53 (53)
No	26.26 (26)
Yes	20.20 (20)

*Some farmers reported having more than one farm activity.

HACCP (11%), Preventive Controls for Human Food (11%), Enhancing the Safety of Locally Grown Produce (10%), Preventive Controls for Animal Food (3%), and Better Process Control (1%). At least 18% of participants reported not receiving any food safety training.

As shown in [Table 3](#), participants identified their top priorities for additional food safety training. The most frequently selected topics, primarily identified by farm owners and managers, were developing a food safety plan (37%), cleaning and sanitizing procedures (34%), and proper produce handling and storage (34%). The least preferred topics included traceability/recall, crisis communication (21%), and best handling practices for post-harvest/wash sanitizer use (19%). Regarding training for employees ([Table 3](#)), the most requested topics were food safety for the harvest crew (39%) and sanitizer monitoring and management (32%). Other areas of interest included personal hygiene (26%), cleaning crew training (22%), and food safety best practices for COVID-19 (13%).

Respondents identified the Alabama Cooperative Extension System (53.5%) as their primary source of food safety information, followed by the Alabama Department of Agriculture and Industries (22.2%) and Tuskegee University (16.15%). Other sources include the Farmers Markets Authority, the Alabama Fruit and Vegetable Growers Association, and the Deep South Food Alliance ([Table 4](#)). Overall, 35% of participants indicated a preference for in-person training formats, while nearly 50% indicated other types of training delivery other than virtual or face-to-face.

Principal Component Analysis (PCA) results

The PCA was used to explore relationships and patterns among participant roles, food safety training, and farming experience, as shown in [Fig. 5](#). The PCA loadings accounted for a substantial portion of the total variance, with Principal Component 1 (PC1) primarily influenced by farming experience and food safety training, and PC2 reflecting variation in farm roles. Results indicate that individuals with

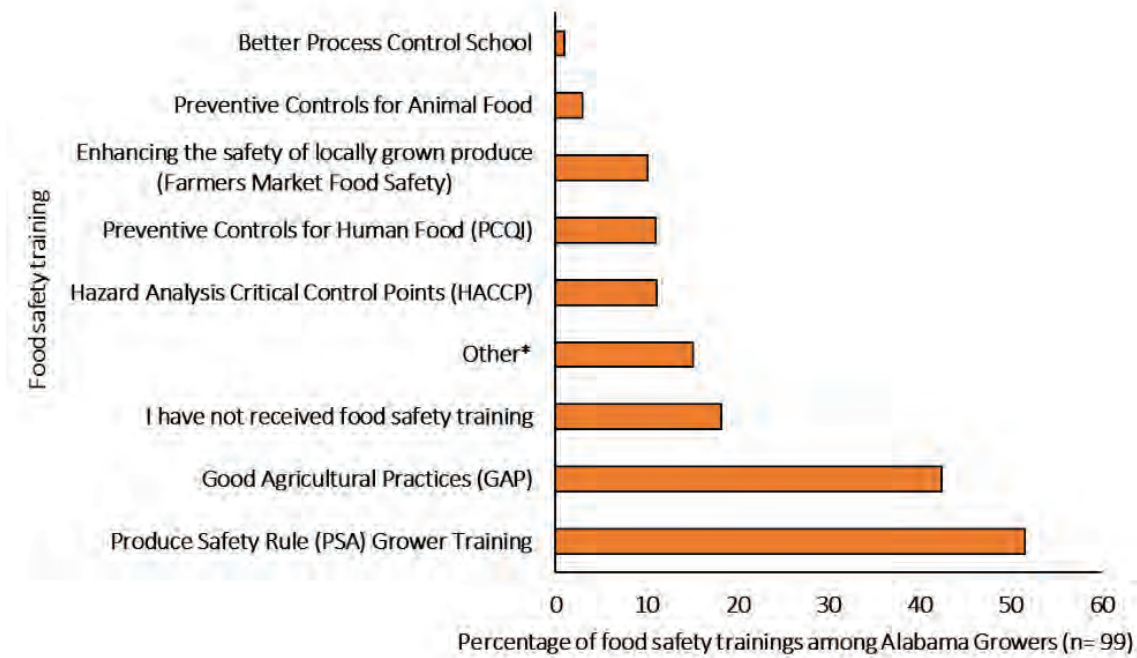


Figure 4. Food safety trainings received by Alabama produce handlers–Needs-assessment Survey (n=99).

* Other: Food Handlers Certificate, training provided by employer or Deep South Food Alliance. Some farmers reported having received more than one training.

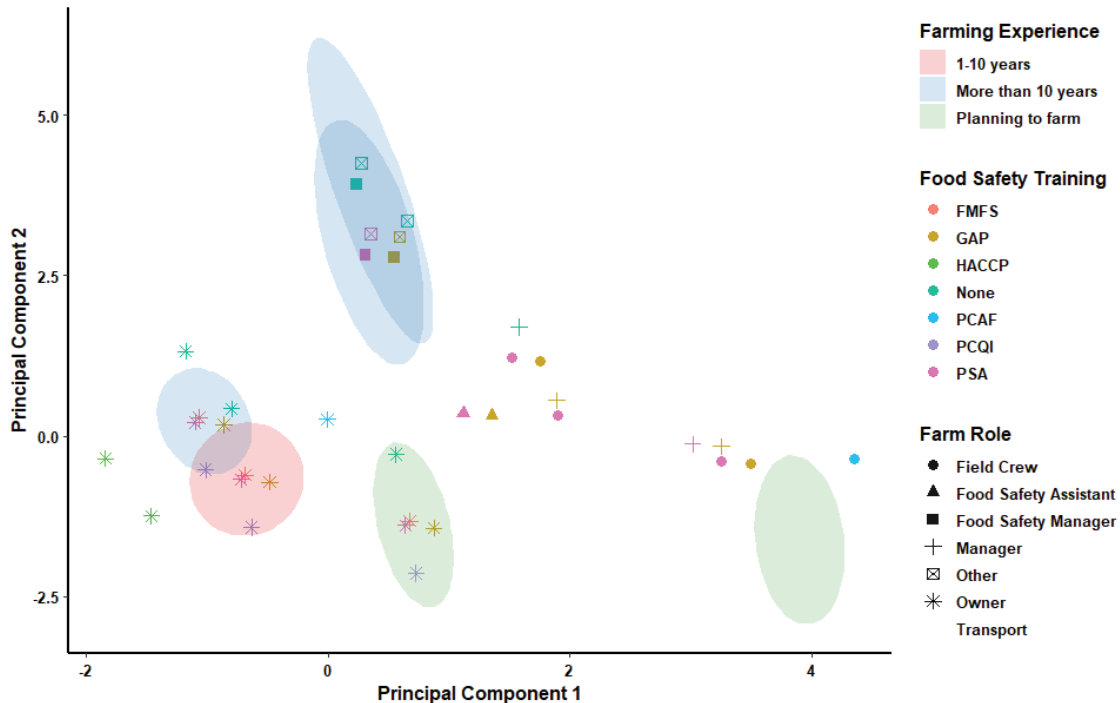


Figure 5. Principal Component Analysis (PCA) of participants based on farm role, years of farming experience, and type of food safety training received.

*Colors represent training types, shapes indicate farm roles, and shaded ellipses group participants by years of farming experience. Abbreviations: FMFS: Farmers Market Food Safety; GAP: Good Agriculture Practices; HACCP: Hazard Analysis and Critical Control Point; PCAF: Preventive Controls for Animal Foods; PCQI: Preventive Controls Qualified Individual; PSA: Produce Safety Alliance.

TABLE 3. Desired food safety topics for further training—Needs-assessment Survey (n = 99)

Food safety topics for further training*	Survey participant % (n)
Grower/ Management	
How to write a food safety plan	37.37 (37)
Cleaning and sanitizing procedures	34.34 (34)
Good produce handling and storage	34.34 (34)
How to properly compost	33.33 (33)
Safe use of soil amendments	33.33 (33)
How to be a better food safety manager (manage employees, productive food safety committee meetings, how to advocate for more resources with ownership, etc.)	30.30 (30)
Co-managing conservation and farm food safety practices	26.26 (26)
Packing facility design and sanitation	24.24 (24)
How to manage a food safety program (how to use data for improvement, what to do with all the data, etc.)	23.23 (23)
How and where to find funding resources for your operation	23.23 (23)
Documentation and record keeping	22.22 (22)
Preparing and responding for a 3rd party audit	22.22 (22)
Pre-harvest water management and treatment	22.22 (22)
Production transportation	22.22 (22)
Traceability/Recall and crisis communication	21.21 (21)
Best-handling practices for post-harvest/wash sanitizer	19.19 (19)
Employee	
Food safety for the harvest crew	39.39 (39)
Sanitizer monitoring and management	32.32 (32)
Personal hygiene	26.26 (26)
Cleaning crew training	22.22 (22)
Food safety best practices for COVID-19	13.13 (13)

*Some farmers reported having received more than one training.

extensive farming experience and formal food safety training (e.g., PSA, GAP, HACCP) clustered together, particularly those with managerial and ownership roles, suggesting a structured and consistent profile within these farming operations. In contrast, individuals with limited experience or no formal training were more distributed across the figure. These findings support the need for targeted outreach and training programs, particularly for beginning growers and those with limited exposure to food safety practices.

AgWater Safety Program

Although over 300 growers were invited to participate in the program, only 20 completed the survey and submitted water samples. These 20 respondents formed the core group

for this phase of the study. A total of 83 water samples were collected from various locations across Alabama (Fig. 2-B). Participant farming experience levels varied, with 55% reporting over 10 years of experience, 35% having less than 10 years, and 10% planning to begin farming. Regarding business size, 55% of participants reported annual produce sales under \$25,000, 20% reported sales between \$25,000 and \$500,000, and 25% chose not to disclose their revenue (Table 5). Participants used a variety of marketing channels to sell their produce, with farmers' markets being the most common (76%), followed by sales to acquaintances, restaurants, and roadside stands. Additionally, two participants (10%) reported selling produce to local schools. Fig. 3-A illustrates the variety of crops grown by

TABLE 4. Communication and training preferences: Needs-assessment (n = 99)

Communication and training preferences	Survey participant % (n)
Source of information about food safety training	
Alabama Cooperative Extension System (ACES)	53.53 (53)
Alabama Department of Agriculture and Industries	22.22 (22)
Other: work, NFU, deep south food alliance	19.19 (19)
Tuskegee University	16.16 (16)
Alabama Fruit and Vegetable Growers Association	14.14 (14)
Social media/ social network	11.11 (11)
Neighbors	10.10 (10)
Farmers Market Authority	5.50 (5)
Alabama A&M University Small Farmers Research Center	5.50 (5)
Commodity groups	4.40 (4)
Beginning Farmers E-newsletter	1.10 (1)
Newspaper	3.33 (3)
Alabama IPM newsletter	3.33 (3)
Radio	1.10 (1)
Training Preference	
Other	50.50 (50)
Face to face	35.35 (35)
Online/Virtual (live webinars)	10.10 (10)
Online/Virtual (pre-recorded videos)	4.04 (4)

TABLE 5. Farm characteristics and demographics of participants–AgWater Safety Program (n=20)

Farm characteristics	Survey participant % (n)
Business size	
Very small business (<\$28 K in produce sales annually)	55.00 (11)
Small business (\$28 K - \$500 K in produce sales annually)	20.00 (4)
Large business (> \$500 K in produce sales annually)	0.00 (0)
I prefer not to answer	25.00 (5)
Marketing channel	
Farmers' markets	76.00 (15)
Wholesales	40.00 (8)
Grocery stores	25.00 (5)
Local schools	10.00 (2)
Others	45.00 (9)
Animal presence	
Yes	25.00 (5)
No	70.00 (14)

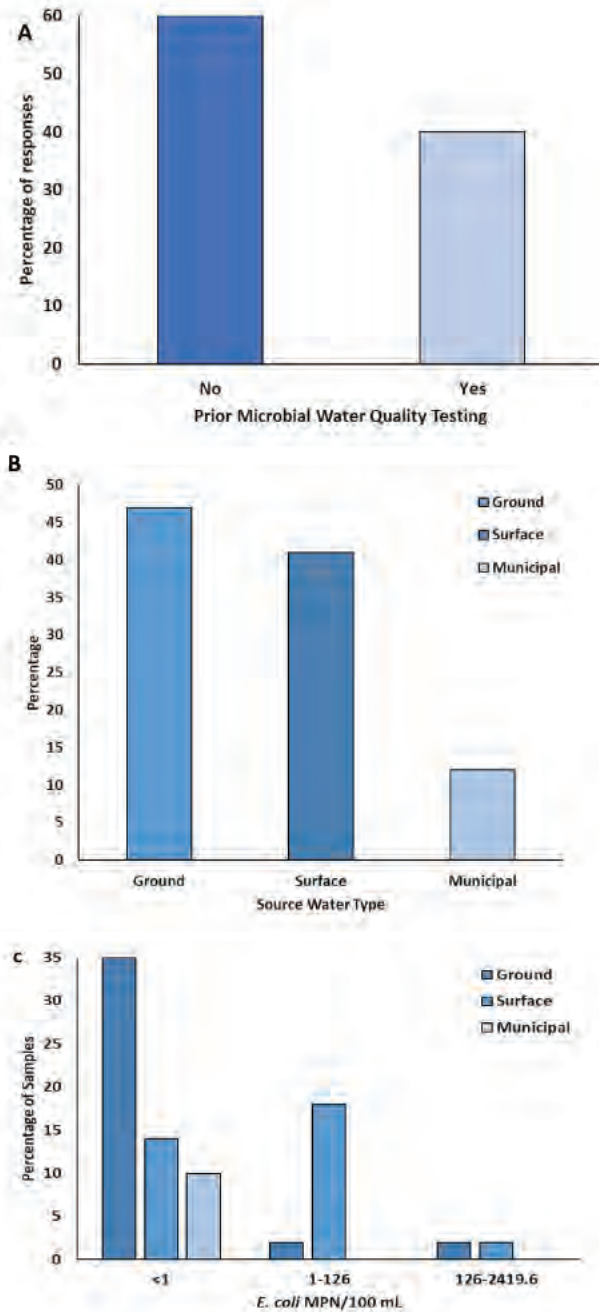


Figure 6. Grower water sampling practices, source types, and prevalence of *E. coli* (MPN/100 mL) in agricultural water. Panel A shows the frequency of growers ($n = 20$) who reported having previously conducted microbial water testing. Panel B displays the distribution of water source types used by growers. Panel C illustrates the percentage of water samples within each source type that fell into three *E. coli* concentration categories: <1 MPN/100 mL, 1–126 MPN/100 mL, and 126–2419.6 MPN/100 mL, indicating varying levels of microbial contamination.

participants. The most commonly reported were horticultural crops (14%), cucurbits and corn (12%), and root vegetables (11%). Smaller proportions grew melons and *Solanaceae* crops (8%), stone fruits (7%), and other crops such as herbs and pecans (5%).

Water sources and prevalence of generic *E. coli*

Of the 20 program participants, 40% had previously tested their water sources, while 60% had not (Fig. 6-A). Farms reported using between one and three water sources, with groundwater being the most common (47%), followed by surface water (41%) and municipal water (12%) (Fig. 6-B). The presence of generic *E. coli* was observed in 24 out of 83 samples (~29%) based on results from the IDEXX Colilert method. Surface water showed the highest prevalence of generic *E. coli*, with 58.82% (20/34) of samples testing positive. No generic *E. coli* was observed in municipal water; only 10% of the groundwater tested positive (Fig. 6). The highest levels of generic *E. coli* were detected in groundwater from 2 different farms, with results exceeding the upper detection limit (> 2416 MPN/100 mL), while the highest surface water level was 920.8 MPN/100 mL.

DISCUSSION

To address the food safety gaps in Alabama systematically, it is important to understand baseline knowledge, demographics, farm practices, and food needs, especially when planning for future programming. The needs assessment survey revealed that 33.7% of respondents self-identify as farm owners, which may be advantageous as farm owners and family businesses tend to have a better understanding of operations and are responsible for decision-making. Understanding the role behind each operation is important, as food safety is about changing people's behavior (42). Notably, 40% of respondents reported either planning to farm or having 1 – 10 years of experience, suggesting this group could benefit from tailored support by Land Grant Universities and Extension Cooperative Systems in adopting food safety practices. Similarly, farmers with over 10 years of experience can continue to develop partnerships with Universities, as 53.5% of respondents reported access to food safety information via the Extension system.

Approximately 75% of respondents reported English as their primary language, contrary to findings in Georgia, where 53% of the farm employees spoke Spanish (33). These differences underscore different educational needs in the Southeast region and highlight that food safety needs to be tailored based on the audience's needs (4, 28, 40). Most survey participants reported owning or working for very small businesses (35%). While very small businesses are often exempt from the PSR, the risks associated with foodborne illness remain, especially since most listed commodities and activities are classified as covered produce under the PSR, except for corn and pecans. Given that many

of these crops have been linked to past outbreaks, continued food safety education and awareness remain essential, especially for small growers who are under less regulatory scrutiny (10).

The findings from the survey highlight critical gaps and opportunities in food safety education among produce growers and their employees. Notably, over 50% of respondents reported completing the PSA grower training, which aligns with the increasing emphasis on compliance with the FSMA. However, the fact that 53% of respondents were unsure whether the regulation applied to them suggests a significant knowledge gap regarding regulatory applicability, which could hinder compliance and risk mitigation efforts. Furthermore, the finding that 20% of respondents had never received any food safety training underscores the need for foundational and refresher training programs. This is consistent with national assessments indicating that many small and mid-sized farms lack access to or awareness of food safety education resources (17). The expressed interest in topics such as writing a food safety plan, cleaning and sanitizing, and postharvest handling reflects a practical orientation toward improving on-farm practices. Extension Cooperative Systems play a critical role in addressing these educational needs. Programs such as the PSA Grower Training, Advanced GAPs, and Packinghouse HACCP are designed to equip growers and employees with the knowledge and tools to reduce microbial risks and meet both regulatory and market-driven food safety standards (7). These programs not only enhance food safety but also support market access and economic sustainability for growers.

The results obtained from the PCA strongly suggest that farming experience and food safety training were the dominant drivers of variance in our survey responses, with farm role emerging as a secondary contributor. This aligns with previous findings indicating that structured training empowers farmers both in safety practices and market opportunities, demonstrating that small-scale producers who undergo food safety training and develop formal food safety plans unlock new market access and improve revenue gains, highlighting the tangible benefits of training interventions (36). These results also demonstrated that individuals combining extensive farming experience and formal training, especially those in managerial roles, tended to cluster together, reflecting a predictable, high-performing profile. In contrast, those planning to farm or lacking formal training appear widely dispersed, signaling variability in knowledge and preparedness. These findings underscore the potential value of designing targeted outreach and training programs tailored to these less experienced or untrained groups, positioning them to achieve more consistent and improved food safety practices.

Phase 1 survey results revealed substantial knowledge gaps among Alabama growers that informed the design of the Phase 2 *AgWater Safety Program*. Although only 40% of

Phase 1 respondents initially expressed interest in water-related topics, 53% were unsure whether the PSR applied to their operations, and 20% had never received any food safety training. In addition, previous studies in Alabama's water sources have detected high levels of enterobacteria associated with foodborne diseases (1, 9). Particularly, epidemiological studies from the CDC in Alabama counties – Wilcox, Lowndes, and Perry – detected a wide range of enteric pathogens (e.g., EPEC, EAEC, STEC, and *Salmonella*) from children's stool samples (9). Authors suggest an increased risk for pathogen detection among children living in homes with well water, compared to children using municipal water (9). Additionally, reports from the Alabama Department of Environmental Management (ADEM) suggest *E. coli* and *Enterococcus* are among the top water pollutants in the state (1). These studies further reinforce the reasoning behind creating the *AgWater Safety Program*, highlighting that using contaminated water poses an elevated risk for Alabamians to become sick from foodborne diseases. The lack of interest in topics associated with water might be due to the lack of awareness on water associated topics, as reported in a prior needs assessment that included growers from Alabama and Georgia highlighted the knowledge gaps in agricultural water topics; more especially, it reported that growers were unaware of how to handle safety and did not recognize water as a microbial risk (16).

Results from the *AgWater Safety Program* align with previous studies showing higher generic *E. coli* from surface water compared to groundwater and municipal water. A study conducted on Alabama's agricultural experimental extension detected generic *E. coli* in 100% (24/24) of surface water and in 2% (1/48) of groundwater (20). In contrast, a lower prevalence of generic *E. coli* was observed from groundwater sources, except for a well that tested positive for the bacteria twice, reaching the upper detection limit. Similar to our findings, the literature suggests that groundwater has been previously recognized as a public health concern, especially in the Black Belt region, where a significant portion of residents solely rely on well water (21, 39). The region has faced challenges due to failing septic systems that led to microbial contamination; in the 90s, it was estimated that 90% of the septic systems in that region were failing due to the local geology (vertosols) (15, 23). Recent studies, including CDC-supported research in Alabama's Black Belt, indicate that private well water sources may pose a higher risk of gastrointestinal illness due to increased contamination with fecal coliforms, compared to municipal water systems (9, 15). Failure to detect a higher prevalence of *E. coli* in well water may reflect the small sample size (n=39). This pilot program can serve as a baseline for further regional food safety programming. Prior to the *AgWater Safety Program*, 60% of participants reported no prior microbial analysis for water. Similar results were reported in earlier studies, where 62.1% of produce growers reported not testing their

irrigation water despite using it (14). Hence, major outreach and more research are needed to identify the true prevalence of generic *E. coli* in groundwater in the state.

Beyond water safety, other challenges that producers in the state encounter include the need for educational tools on food safety and food safety practices (9, 14, 16, 20, 26, 32). A study conducted in 2014 by Tuskegee University highlighted barriers such as a lack of resources and clarity, and a need for financial assistance (40). Researchers identified that growers resist applying food safety practices due to cost and access to funding (40). Considering that our program is free of cost, it is beneficial for growers and tackles financial constraints. Other food safety limitations for specialty crop growers in Alabama include a lack of educational resources, time commitment, and cost (29). While nearly 100 participants completed the needs assessment survey, only 20 enrolled in the water program, which might not represent the entire state of Alabama. Several factors may have contributed to low engagement and enrollment into the program, including limited awareness of the program's relevance and perceived complexity or cost associated with water sampling and submission. Future efforts should consider simplifying participation logistics, offering incentives, and increasing outreach through trusted community channels to improve grower involvement and ensure broader representation in water safety assessments.

CONCLUSIONS

This exploratory study elucidates key food safety needs among Alabama produce growers and highlights the need for increased awareness and outreach on food safety-related topics. A program focused on microbial quality of water for agricultural purposes was established in response to identified gaps. Results showed that surface water generally carried higher microbial loads compared to municipal and/or well

water. However, the highest concentrations of generic *E. coli* were detected from a well, exceeding the method's detection limit. Our findings reinforce the importance of assessing the microbial quality of Alabama water used for agricultural purposes. It is important to note that findings from the *AgWater Safety Program* are based on a small number of participants and should be interpreted as preliminary insights rather than representative of the broader grower population. The limited sample size constrains the extent to which these results can be extrapolated. Further research is recommended to assess the prevalence of pathogens and indicator organisms in water sources across a wider range of farms. Such data will be essential for guiding Alabama's produce industry's evolving food safety needs. Overall, these results demonstrate the importance of tailoring training and outreach efforts to growers' experience levels while also addressing critical on-farm risks such as water quality.

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

No AI or AI-assisted technologies were used in any phase of this manuscript's development and writing.

Supplemental Materials are available [HERE](#).

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