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2900 100th Street, Suite 309, Des Moines, IA 50322-3855, USA

Rebecca Stearns,[1] Wentao Jiang,[1] Janet Tou,[1] Kristen Matak,[1] Annette Freshour,[1] Timothy Boltz,[2] Jacek Jaczynski,[1] Carly Long,[1] and Cangliang Shen[*]

[1]Division of Animal and Nutritional Sciences, West Virginia University, Morgantown, WV 26506, USA

[2]Department of Poultry Science, Mississippi State University, Mississippi State, MS 39762, USA

A Preliminary Pilot Farmers' Market Survey of the Triple-Wash Method: A West Virginia Farmers' Market Survey of Very Small Produce Growers' Knowledge of Microbial Contamination and Their Perception of the Triple-Wash Method

ABSTRACT

Fresh produce sold at local farmers' markets (FMs) was identified as a source of microbial contamination. In this study, a survey was developed to analyze small and very small produce growers' knowledge of food safety. The questionnaire also assessed producers' familiarity and willingness to implement the triple wash method (TWM). Surveys were conducted at FMs in West Virginia. The survey included demographics, knowledge of microbial cross-contamination on produce, washing strategies, awareness of the TWM, and willingness to attend good agricultural practice/ Food Safety Modernization Act (GAPS/FSMA) and TWM training. Data were analyzed using Chi-square test ($P < 0.05$) in R-software. A total of 82 vendors participated in the survey. The survey results revealed knowledge gaps about food safety among FM produce vendors. Additionally, 53.7% of FM vendors did not wash their produce due to increased spoilage (52.6%; $P < 0.05$). Among participants who washed produce, only 28.2% were familiar with the TWM. Most respondents who washed produce (65.3%; $P < 0.05$) stated they would be interested in attending GAP/FSMA and TWM training. The information obtained from this study will help tailor GAP/FSMA and TWM training provided by regional extension offices.

INTRODUCTION

The United States Department of Agriculture's (USDA) Agricultural Marketing Service (AMS) reported exponential domestic growth of 1,755 to 8,771 local Farmers' Markets (FMs) from 1994 to 2019 and since then the number of FMs has remained stable *(58)*. The increasing number of FMs can be attributed to the widespread opinion that produce sold at FMs is "healthier" than grocery store products *(8)*. The reason for this opinion is because fruits and vegetables sold at FMs are typically in season and picked at peak ripeness to maintain vitamin and mineral content *(8)*. According to the 2019 National FM Managers' Survey, approximately 67% of FM vendors reported an increase in production and 33% stated they need to increase the number of employees in order to meet this demand *(48)*. This business success has also been seen in West Virginia (WV) FMs *(65)*.

*Author for correspondence: Phone: +1 304.293.2691; Fax: +1 304.293.2232; Email: cangliang.shen@mail.wvu.edu

Farming in WV contributes $800 million annually to the state's economy. In WV, there are nearly 20,000 farms and over 200 FMs. According to the 2022 WV FM Census Aggregate Data Analysis Report, registered FMs has tripled from 91 to 284 in 2017 to 2022 *(25)*. The 2019 Fresh Food Act (FFA) and Supplemental Nutrition Assistance Program (SNAP) have contributed to the amount of money spent on locally grown produce by schools and consumers. The 2019 FFA mandates state-funded institutions, such as schools purchase at least 5% of their products from local farmers. Also, SNAP Stretch encourages families to buy produce from FMs by offering a 1 to 2 match for their SNAP/ Electronic Benefits Transfer (EBT) on the purchase of fruits and vegetables *(67)*. In 2021, customers spent approximately $275 each time they visited an FM *(25)*. In 2022, it was estimated that over 12,000 patrons visited FMs weekly *(25)*.

Given the growing popularity of FMs and their contribution to the local and national economy, it is crucial that produce sourced from local farms be microbiologically safe for consumption. In addition to consumers' perception that local produce are healthier than produce commonly found at large supply-chain grocers, many consumers perceive that produce from an FM is also safer to eat *(12, 60)*. In contrast to this belief, a recent microbial surveillance study of FMs revealed high contamination rates of *Salmonella* and *Listeria* spp. on produce *(33)*. In addition, contaminated cantaloupe, strawberries, blackberries, and tomatoes sold in FMs caused outbreaks of *Escherichia coli* O157:H7 and *Salmonella* in the U.S. *(13, 27, 44)* Shelled peas sold in FMs from Wisconsin and Alaska were associated with *Campylobacter jejuni* and *Salmonella* outbreaks *(14, 62)*.

Nationally, poor agricultural practices from large-scale growers have also led to pathogenic bacteria cross-contamination on fresh produce and caused several outbreaks *(7, 16, 37, 39, 42, 45)*. An epidemiological study conducted from 1998 to 2008 by the Centers for Disease Control and Prevention (CDC) estimated approximately 4.9 million (51%) of the 9.6 million foodborne illnesses were attributed to plant commodities. Produce commodities, including fruit, nuts, and vegetables, accounted for 46% of annual illnesses. Leafy vegetables were associated with the most produce commodity-derived foodborne illnesses. In 1982–2008, outbreaks related to produce included *Escherichia coli* (*E. coli*) O157 *(39, 42, 45)*, *Salmonella* spp. *(9, 11, 37, 59, 61)*, and to half of Norovirus-related illnesses *(16, 37)*. Another study reported that eighty-five multistate foodborne illness outbreaks from 2010 to 2017 in the U.S. were associated with fresh produce contaminated with pathogenic *E. coli*, *Listeria monocytogenes* (*L. monocytogenes*), and *Salmonella enterica* (*S. enterica*) due to poor agricultural practices *(7)*. The instances of food-borne illness outbreaks originating from produce, show that produce can be sources of contamination, which is why GAPs are important in large and small industries.

An FM consumer survey in WV, KY, and PA found approximately 54% of participants were slightly worried or not worried at all about produce microbial safety at FMs compared to 26.3% of respondents who were very or extremely concerned. Among respondents, 30.5% considered cleaning produce was the FM vendors' responsibility, whereas 26% thought the responsibility belonged to the consumers, and 9.2% thought the government or food inspection agency should manage food safety at FMs *(42)*. Another FM consumer survey showed the majority of consumers agreed monitoring the safety of their produce was the farmer's responsibility *(21)*. There are federal food safety guidelines i.e., good agricultural practices (GAPs) defined in the "Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables" *(56)* and the Produce Safety Rules in the Food Safety Modernization Act (FSMA)*(54, 55)* for produce growers to follow. However, the average net profit for most produce growers at FMs in WV is less than $25,000 which exempts these vendors from the regulations under the FSMA *(54)*. The FDA's FSMA is the set of minimum standards for growing and processing produce for human consumption, and it serves as food safety guidance for other agencies and processes such as the USDA's GAPs certification. Small and very small growers in WV can obtain GAPs certifications from the USDA if they undergo food safety audits *(48)*. The USDA's 's audits check to see if growers follow the FDA's Guide to Minimize Microbial Food Safety Hazards for Fresh Fruits and Vegetables. Even though local growers may be exempt from the FDA's regulations, it is important they understand the good agricultural practices explained in those regulations *(48, 56)*. Similar to most states, vendors at FMs in WV are subject to local food codes i.e., the WV code §19-35-5, *Potentially hazardous foods*. This code states that the public health department shall regulate potentially hazardous foods, which are defined as foods that require temperature/time controls or other protocols that limit pathogenic bacteria growth *(68)*. However, according to the WV department of Agriculture, fresh produce is considered potentially hazardous and vendors selling fresh produce at WV FMs should meet the current FDA's FSMA Produce Safety Rule's requirements, although the exception is granted if the farms 1) sold less than $25,000 average annual produce during the previous three-year period; 2) average < $500,000 in food sales annually (for the last 3 years); and 3) sell most of their food within the state or 275 miles or less from the farm *(66)*. Produce wash water with sanitizer in recirculated water systems can be an effective preventive control for microbial cross-contamination of bacteria *(15)*. The FSMA Produce Safety Rule does not require post-harvest produce wash; however, this community outreach project focused on very small local produce growers in WV to whom the triple-wash may be required by the largest wholesale distribution company in the WV area. This distribution company purchases from several farms across WV, including Turnrow Appalachian Farm Collective in southern WV, which aggregates produce from 120 very small local produce growers in the state. As the awareness of food safety requirements have increased, more growers are interested in learning about new technologies for reducing surface bacteria on their products.

Therefore, the WV Small Farm Center (WVU-SFC), a member of the WV Food Safety Training Team, promotes the application of the triple wash method (TWM) on raw produce grown close to or on the ground by local produce growers and offers video training *(30)*. The TWM is a series wash method consisting of three immersion tanks in which produce is submerged to clean and remove debris from the surface. The TWM can be used with or without antimicrobials but if antimicrobials are used then they can be added to the first (antimicrobial, water, water (AWW), second (water, antimicrobial, water (WAW), or third (water, water, antimicrobial (WWA) series wash. Although it is not mandated that growers use the TWM to wash produce, it was included in this survey because it is recommended by the WVU-SFC and because a popular wholesale distribution company and buyer of local produce requires growers who sell to them to use the TWM. Additionally, several studies found that the TWM effectively reduced pathogens from the food surfaces of different produce commodities *(6, 30, 31, 32, 46, 47)*. However, FM growers' knowledge of GAPs and the TWM has not been assessed.

Due to the ambiguity of the term "other protocols" in the WV code §19-35-5 *(68)*, lack of federal regulations enforced upon small growers *(54)*, consumer agreement that farmers should be in control of food safety for their products, and minimal studies analyzing food safety of vendors at FMs *(3, 64)*, it is important to assess the food safety knowledge of produce vendors at FMs. This study conducted an outreach survey of vendors selling produce (fruits and vegetables) at local FMs in multiple locations across WV. This self-reported survey was conducted to determine the growers' knowledge of food safety regarding post-harvesting practices, understand current practices implemented by local growers, and analyze their familiarity and willingness to implement the TWM.

MATERIAL AND METHODS

Survey Development

The survey (see addendum) was developed in collaboration with the WVU-SFC to ensure participant relevance. The study was approved by WVU Institutional Review Board (protocol #2307818674). The survey questionnaire comprised 24 multiple choice questions with two to fifteen choices per question. Questions consisted of participants' demographic information (i.e., age, gender, education, zip code, size of acres farmed, years as a vendor at a WV FM), knowledge of the safety of fresh produce, and awareness and perceptions of the TWM. The complete survey is provided as Supplement 1. The survey was conducted using paper ballot surveys and online surveys through the period of May to September 2022 and 2023. Links or QR codes to the Microsoft® Forms online surveys were sent or given to farmers who were unable to complete the survey at the time of visitation and to those whom it was not feasible to be seen in-person. Participants were informed that the survey was voluntary and anonymous, and they were free to withdraw at any time. A total of 86 surveys were handed out to vendors at FMs across WV. WV-FM Census Aggregate Data Analysis reports that there are approximately 248 FMs in WV as of 2022. Based on the conservative estimation of 5 produce vendors per FM, we calculated that there would be a total of 1240 produce vendors in the state; therefore, the estimated power of the total 86 surveys represented 7.0% of produce vendors in WV. These surveys were from three of the most populated cities in WV (Morgantown, Huntington and Charleston), as well as less populated areas in western WV. Due to the low number of participants, this project can be recognized as a preliminary pilot study for our future FSMA related outreach survey studies. Of the surveys handed out, 82 were returned, resulting in a response rate of 95.3%. The response rate for each question was 95.1–100%. Of the surveys received, 21 were completed online and 61 were paper ballots. All survey data received from online and paper questionnaires was first recorded on paper and then merged together and inputted into an Excel spreadsheet (Microsoft, Redmond, WA) for statistical analysis. In order to validate the survey questions and ensure they were relevant to local FM growers and easy to understand, the survey questions were sent to WVU extension experts and local farmers before research began. The questions were adjusted and reworded based on the validity assessment from the small scale (~6 participants) pre-test at 2022 WV-SFC. Returned questionnaire sheets were checked immediately by the author's team to make sure the clicked answers are reliable and the author's team member explained and even read off some questions to the participants who had questions/concerns during the survey. Data recorded by graduate students were also rechecked by the corresponding author.

Data Analysis

Statistical analysis was performed after merging online and paper ballot survey results. Validation procedures were performed by cross-referencing the merged data set with initial results to ensure consistency. The hypothesis of this survey is that the participants' (small and very small local produce growers) frequency of answer choices of every question will be different; therefore, the Chi-square tests of frequencies from *Tables 1 to 9* were used to test the difference ($P < 0.05$) from R-software. For *Table 9*, the bivariate relationships between the education levels, knowledge of foodborne pathogens, and potential sources of contamination on farms were also tested ($P < 0.05$).

RESULTS AND DISCUSSION

Demographics

Table 1 shows the demographics of participants. Most survey participants were male (52.4%; $P < 0.05$) and between the ages of 36–45 (23.2%; $P < 0.05$). Other studies found that the majority of FM survey participants were female (50–53%) and approximately 26% of the participants were middle-aged *(19, 23)*. A FM survey in Kentucky (KY) also showed that most vendors (54.4%) were middle aged males *(43)*. In this present study, female participants made up 41.4% of the target demographic, whereas 4.9% of participants preferred not to specify their gender.

Furthermore, 71.6% of participants had some form of higher education with 62% of the WV FM vendors having at least a bachelor's degree *(23)*. Jiang et al. (2021) found that 24.7% of the WV FM vendors had at least a high school degree or GED (24.7%), with only 3.7% stating that they had fewer than 12 years of education ($P < 0.05$) *(23)*. Most surveyed WV FM vendors had less than five years' experience in selling produce at WV FMs (39%; $P < 0.05$), whereas 23.2%, 18.3%, and 19.5% had 6–10, 11–20, or over 20 years' experience, respectively. The most acreages owned by produce farmers was 1 to 24 acres (47.6%; $P < 0.05$), followed by less than 1 acre (23.2%; $P < 0.05$) of harvestable land. Only 12.2% of farmers reported having over 100 acres of land in production ($P < 0.05$). The results indicated most of the surveyed FM vendors were small to very small produce growers.

Prevalence of washing produce for procurement

The types of produce sold at WV FMs are shown in *Table 2*. The most ($P < 0.05$) common produce grown were cucumbers and tomatoes (87.8%), followed by root vegetables (69.5%), fruits grown on or near the ground (58.5%), leafy vegetables (58.5%), and fruits grown on bushes or trees (52.4%) *(Table 2)*. Small and very small produce growers often grow various types of produce depending on the harvest season and therefore, participants were asked to choose more than one answer if applicable. Participants were given the option to write responses if they chose the answer choice "other." Of the 19.5% of participants that stated that they grew "other" produce that were not listed, responses included microgreens (2.4%), corn (8.5%), mushrooms (3.7%), grains (1.2%), okra (1.2%), and beans (1.2%). Over half (58.5%) of the produce grown by WV local growers were fruits grown on or near the ground, such as cantaloupes, strawberries, and melons. Produce grown near soil are at higher risk of bacterial contamination than produce with the edible portion grown further away from the ground *(50)*. The WV SFC encourages applying the TWM to reduce microbial pathogens during their post-harvest processing *(30, 31)*.

When asked whether vendors wash their produce before selling them at local FMs, 53.7% stated that they did not wash their produce and 46.3% said they did ($P < 0.05$, *Table 3*). In contrast, our previous survey conducted in KY FMs found 84% of growers washed their produce before selling it to the public *(41)*. In the present study, participants stated that they did not wash their produce because washing causes produce to spoil faster (52.6%). Other reasons growers did not choose to wash their produce included washing required too much labor involvement (27.2%), washing is too costly (13.6%), and washing does not help decrease microbial risk (9%) $P < 0.05$ *(Table 3)*. Additionally, 2.3% of participants responded that it was the consumers' responsibility to wash their produce at home and 2.3% stated they were not GAP certified to wash produce *(Table 3)*. A previous survey study of vendors and consumers at FMs across the U.S. revealed vendors had minimal food safety education, and consumers did not view produce as a high contamination risk and thus, had no concerns regarding products *(63)*. The results from Worsfold et al., (2004) suggested it was unlikely consumers washed their produce at home *(62)* despite the FDA and the Partnership for Food Safety Education recommending consumers always wash their produce *(55)*.

Previous FM microbial surveillance studies *(29, 33, 38, 40, 63)* indicated that produce sold at outdoor markets have possessed pathogen contamination. Park et al., (1992) identified the occurrence of thermotolerant *Campylobacter jejuni, coli,* and *lari* at 533 FMs on six different types of vegetables. In contrast, supermarket vegetables were negative. The study results raise concern of microbial contamination on produce sold at FMs *(38)*. Additionally, native, non-pathogenic flora such as aerobic bacteria, coliforms, and generic *E. coli* were present on tomatoes, leafy greens, and berries in Florida FMs *(40, 63)*. Spinach (2.6%) and leafy greens (3.9%) at FMs in FL also tested positive for *L. monocytogenes (40)*. In Washington state and California FMs, one parsley sample tested positive for *Salmonella* and 24.1% of samples were positive for generic *E. coli*. *(29)*. Our recent FM surveillance study conducted in WV and KY found that almost 4% of all produce tested were positive for *Listeria monocytogenes*. 10–19% of tomato, spinach, and pepper samples were confirmed to be positive for *Salmonella* spp. *(33)*.

The presence of foodborne pathogens in a high percentage of samples indicates a critical need to understand the cause of contaminated produce (e.g., soil, manure, and agricultural water) and need for training on mitigation strategies to reduce foodborne pathogens on locally grown,

TABLE 1. Farmers' market vendors' demographics, farmers' market experience, and the harvestable acres owned

	Frequency	%	*P*-value of Chi²
Gender (n=82)			< 0.05
Male	43	52.4	
Female	34	41.4	
Other	1	1.2	
Prefer not to answer	4	4.9	
Age (n=82)			< 0.05
18–25	5	6.1	
26–35	18	22	
36–45	19	23.2	
46–55	18	22	
56–65	10	12.2	
66+	12	14.6	
Education (n=81)			< 0.05
Fewer than 12 years of schooling	3	3.7	
High school graduate or GED	20	24.7	
Associate or technical degree	18	22.2	
Bachelor's degree	25	30.9	
Graduate degree (Master's, Professional, or Ph.D.)	15	18.5	
Years as market vendor/farmer (n=82)			< 0.05
< 5 years	32	39	
6–10 years	19	23.2	
11–20 years	15	18.3	
>20 years	16	19.5	
Harvestable Acres (n=82)			< 0.05
<1 acre	19	23.2	
1–24 acres	39	47.6	
25–49 acres	7	8.5	
50–74 acres	4	4.9	
75–99 acres	3	3.7	
>100 acres	10	12.2	

fresh produce. The development of fact sheets and handbooks tailored toward very small local produce growers to address the knowledge gap between FSMA regulations and practices may be beneficial.

Methods of Washing Produce

Table 4 shows the produce washing methods used by WV FM vendors. Of the 38 vendors that reported washing their produce, 28.9, 5.3, 73.7, 2.6, 7.9, and 2.6% ($P < 0.05$) used tested well water, untested well water, municipal water, rainwater, and spring water sources, respectively. None used surface water to wash their produce. The most common (78.9%; $P < 0.05$) method utilized for washing produce was running water (i.e., sprayer or sink), followed by using a wash table (31.6%) and then tubs or containers (26.3%). In addition, 5.3% of participants used an unspecified alternative method of washing produce e.g., spring water *(Table 4)*.

For farmers using untested agricultural water, physical treatment or a pesticide device may be needed to ensure water is safe for its intended use and to minimize the risk

TABLE 2. Frequency of types of produce grown by farmers' market vendors

	Frequency	%	*P*-value of Chi²
Types of produce grown (n=82)			< 0.05
Leafy vegetables (e.g., lettuce, spinach)	48	58.5	
Other vegetables (e.g., tomatoes, cucumbers)	72	87.8	
Fruits grown on bushes or trees (e.g., blueberries, blackberries, and apples)	43	52.4	
Root vegetables	57	69.5	
Fruits grown on or near the ground (e.g., cantaloupe, strawberries, and other melons)	48	58.5	
Other*	16	19.5	

*Note: The answer choice "Other" included the following written responses: "microgreens" (2.4%), "mushrooms" (2.4%), "grains" (1.2%), "okra" (1.2%), "beans" (1.2%), and "corn" (7.3%).

TABLE 3. The frequency of washing produce and reasons vendors decide not to wash produce before selling them at farmers' markets

	Frequency	%	*P*-value of Chi²
Do you wash your produce? (n=82)			> 0.05
Yes	38	46.3	
No	44	53.7	
Reasons farmers/vendors decide NOT to wash the produce (n=44)			< 0.05
Washing causes produce to spoil faster	27	52.6	
Washing adds too much labor	12	27.2	
Washing adds too much cost	6	13.6	
Washing does not decrease microbial risk	4	9	
Other*	6	13.6	

*Note: "Other" included the following written responses; "It is the consumers' responsibility (2.3%)," "Produce requires refrigeration after washing (2.3%)," and "Not Good Agriculture Practices (GAP) certified to wash (2.3%)."

of contaminants in the water *(37)*. However, if treatment is used, it must be monitored frequently *(55)*. One standard for produce wash water laid out by the FSMA, but not required for small growers, is that produce wash water should have zero detectable generic *E. coli* per 100ml of water *(51, 53)*. Alternatively, if produce is sensitive to washing or clean water is not available, then dry washing is an acceptable method of cleaning produce to help remove visible dirt along with some contaminants *(56)*. If growers use serial washes such as the TWM, the final rinse before packaging must be as clean as possible. Also, if wash waters are being re-used, water should flow counter-current to produce in differing operation units *(56)*. Washing with brushes is also recommended as a best practice *(56)*.

However, validation studies have shown that washing vegetables in water alone can only reduce pathogen cells by at most 1.62 log CFU/g *(4, 5, 26)*.

Of the 38 vendors in this study who washed their produce, 36 responded to the question of sanitizer use in their wash water. The majority 72.2% ($P < 0.05$) responded they did not use sanitizer *(Table 4)*. In the present study, 27.8% ($P < 0.05$) said they did use sanitizer in their produce wash water. Those who used sanitizer reported adding bleach (sodium hypochlorite) (50%) to their wash water. Other sanitizers used were H_2O_2-PAA (20%), vinegar (acetic acid) (20%), and baking soda (bicarbonate) (10%). According to the U.S. FDA, 0.5% of baking soda has weak microbicidal activity and may take 1–60 min to kill certain

TABLE 4. Frequency of sources of wash water, wash methods, sanitizers in wash water, and wastewater treatment methods used by farmers' market vendors

	Frequency	%	*P*-value of Chi²
Sources of wash water (n=38)			< 0.05
Tested well water	11	28.9	
Untested well water	2	5.3	
Municipal water	28	73.7	
Surface water	0	0	
Rainwater	1	2.6	
Other:	3	7.9	
Wash methods used (n=38)			< 0.05
Tub or other containers	10	26.3	
Running water (i.e., sprayer, sink)	30	78.9	
Washing table	12	31.6	
Other	2	5.3	
Do you add sanitizer to your wash water? (n=36)			< 0.05
Yes	10	27.8	
No	26	72.2	
Sanitizers used in wash waters (n=10)			No statistical power
SaniDate	2	20	
Bleach	5	50	
Vinegar	2	20	
Baking soda	1	10	
If you use sanitizer, how often do you change sanitizer water? (n=38)			< 0.05
Within 4 hours	11	28.9	
Between 4–12 hours	3	7.9	
Between 12–24 hours	1	2.6	
Within 4 hours	3	7.9	
Not at all	20	52.6	
How do you treat your produce wash wastewater? (n=32)			< 0.05
Simply dump them.	25	78.1	
Chlorinated	4	12.5	
Ozonated	0	0	
Others:	3	9.3	

*Note: Some participants chose more than one answer.
One individual specified using spring water as a wash water source (2.63%).
The sanitizers used in wash waters were written responses from participants.
The answer choice "Other" included the following written responses: "H_2O_2" (3.1%) and "Water other crops if the water is clean enough." (3.1%)

types of bacteria and viruses on inanimate objects *(10)*. Bicarbonate also proved ineffective at reducing pathogens such as *L. monocytogenes* on leafy vegetables compared to turmeric extract, black pepper extract, and sodium chloride. Vinegar (8%) and sodium chloride are considered "minimal risk" pesticides *(53)*. Vinegar was found to be less potent compared to lactic acid for reducing *Salmonella* and *E. coli* on cucumbers or reducing *Shigella* spp. on lettuce *(1, 20, 70)*. Additionally, Kilonzo-Nthenge et al., (2019) found that bleach containing 200 ppm of HClO (free chorine) was the most effective household sanitizer for reducing *Salmonella* spp. on spinach compared to vinegar and baking soda *(26)*. According to the U.S. FDA household bleach has a wide range of antimicrobial activity that is fast-acting and inexpensive, and it can remove dried organisms and biofilms *(10)*. The agency also stated that used properly, bleach is recognized as safe for household and environmental use *(10)*.

In addition to chlorine, H_2O_2-PAA, is an effective agent for reducing and preventing microbial cross-contamination of pathogens including *Salmonella* Typhimurium, and *L. monocytogenes*, and *E. coli* O157:H7 on produce *(8, 9, 11, 16, 28, 29, 34)*. Very small and small produce growers in WV who use the TWM to clean produce are required to use a H_2O_2-PAA disinfectant if they sell to a wholesale distribution company in Duffield VA; however this antimicrobial is not a national requirement *(30, 31)*. This company purchases produce from several farms across WV, including Turnrow Appalachian Farm Collective in southern WV, which aggregates produce from 120 very small produce growers in WV *(30, 31)*. However, the current survey results indicate that only 20% of the survey participants used H_2O_2-PAA to wash their crops. The results indicate a critical need to develop community outreach activities that expand the current produce safety training program to include TWM training using H_2O_2-PAA. to assist very small produce growers in WV. The outreach project could fulfill the washing requirements from their buyer but emphasize that produce preharvest controls such as soil, manure and compost management are important for microbial safety.

Additionally, produce safety and GAPs training in WV should include proper changing and disposing of wash water. Of the 38 survey participants responding to the question of changing of produce wash waters, 52.6% stated they never changed the water, 28.9% said they changed the wash water within 4 h, 7.9% change the water between 4–12 h, and 2.6% change the wash water between 12–24 h ($P < 0.05$). Before disposing of wash water, 12.5% treat their wash water with chlorine and 3.1% use hydrogen peroxide as a post-wash treatment. However, the majority (78.1%) of the survey participants do not treat their waste wash water or use chlorine or ozone ($P < 0.05$) *(Table 4)* and 3.1% of participants use wash water visually clear of debris to water other crops. One reason the majority of participants stated they do not treat or change their produce wash water could be because most of the participants that wash their produce use running water; therefore, changing and treating wash water is not needed. If immersion methods like the TWM are used the wash water should be monitored for pH, turbidity, debris, sanitizer concentration, and temperature to determine whether it needs replacing or thrown out. Wash water not continuously monitored may result in the buildup of microbial loads. Further, wash water should be changed between different types of produce *(55)*. Sanitizers used must be compounds listed on the EPA's registry and can be used to treat agricultural wash waters. Peracetic acid (PAA), ozone, chlorine dioxide, and sodium hypochlorite (chlorine bleach) are listed as acceptable commercial sanitizer/pesticide according to the FDA (21CFR 173.315) and the EPA (Section 3-40 CFR 152.25(a)—regular registration) *(36, 49, 52, 57)*. The present survey study reported there was no use of compounds recognized as harmful by either governing agency.

Awareness and Preferences of the Triple Wash Method

Of the 44 participants who washed produce to sell at WVFMs, 39 responded to the question regarding either awareness or unawareness of the TWM. Of the participants, 28.2% reported they were familiar with the TWM, whereas 87.5% were not ($P < 0.05$) *(Table 5)*. Since only 11 individuals self-reported they knew about this wash method, this sample size did not have enough statistical power to determine significance. However, of the 11 respondents 54.5% said if they were to implement the TWM they would prefer to use the water, water, antimicrobial (WWA) method, 18.2% would prefer the water, antimicrobial, water (WAW) process, and 27.3% would use the antimicrobial, water, water (AWW) process *(Table 5)*.

Our previous studies indicated that the TWM using H_2O_2-PAA solutions, lactic/ citric acid blends, and sodium hypochlorite were effective at reducing microbial loads and cross-contamination of *Salmonella* spp. and *Listeria* spp. on butternut squash, spinach, cucumbers, and tomatoes *(30, 31, 32, 33, 46, 47)*. Applying antimicrobials to the last water wash container (WWA) was the most effective at reducing and preventing cross-contamination of pathogens on produce *(30, 31, 46, 47)*. The addition of antimicrobials in wash waters has proven to be an effective method for reducing pathogen cell transfer on produce, if not reducing cells on contaminated produce *(15, 46)*. However, this information is not widely available to local produce growers.

The lack of awareness of the TWM may be due to limited outreach/extension training opportunities. Shown in *Table 6*, 51.2 % ($P < 0.05$) of the survey participants stated they wait to see others' successes using new technology before implementing it by themselves. Only 14% and 23.3% of

TABLE 5. Frequency of farmers' market vendors' awareness of the three-step wash process and their preference for the water, water, antimicrobial (WWA) or water, antimicrobial, water (WAW), or antimicrobial, water, water (AWW) processes

	Frequency	%	*P*-value of Chi²
Have you heard of the three-step wash process? (n=39)			< 0.05
Yes	11	28.2	
No	28	87.5	
If yes, which process would you use? (n=11)			No statistical power
Water, water, antimicrobials (WWA)	6	54.5	
Water, antimicrobials, water (WAW)	2	18.2	
Antimicrobials, water, water (AWW)	3	27.3	

TABLE 6. Farmers' market vendors' attitude and willingness to try new agricultural technology

	Frequency	%	*P*-value of Chi²
Please select the statement below that best describes your attitude towards new technology and production methods. (n=43)			< 0.05
I am always the first to try new technologies.	6	14	
I am one of the first to try new technologies.	10	23.3	
I normally wait to see other's success with new technologies.	22	51.2	
I am one of the last to try new technologies.	3	7	
I never try new technologies.	2	4.7	

participants responded that they were the first or one of the first to try new technologies, 7% answered that they were the last to try new technologies, and 4.7% never try new technologies. The results indicate that until TWM outreach information is more widely distributed across the state, the popularity of applying this method will be limited among growers who sell produce at WV FMs.

Considerations for adopting the TWM

As shown in *Table 7*, the top three reasons participants indicated they would consider adopting the TWM would be if it is easy to implement (86.8%), can be adopted at low cost (68.4%), and if it is easy to integrate with existing practices (55.3%). Other reasons ranked in the following order from the most to least important: easy access to TWM information (36.8%); high efficacy in lowering microbial risk (34.2%); high perceived economic value (28.9%); standardized procedure (21.2%); high adoption rate among fellow farmers (13.2%); good technical support (13.2%); and government support (10.5%) ($P < 0.05$), respectively *(Table 7)*. A written response from two participants was "low risk of exposure to consumers and workers." Our previous studies demonstrated, using a standardized process, the TWM is easy to integrate and effectively reduces microbial risks (*30, 31, 45, 46, 47*). The highest microbial reductions was 3.53 and 3.42 $\log_{10}$MPN/g using the WAW and WWA method with 0.25% H_2O_2-PAA (96 ppm of PAA within EPA label requirement) on *Salmonella* Typhimurium inoculated tomatoes *(45)*.

The financial considerations for adopting the TWM were also surveyed in this study, and the results are reported in *Table 7*. Survey participants were asked "what an acceptable increase in production cost would be if they did not increase the price of their product" based on the assumption that the TWM decreases microbial risks by 5%. Based on those parameters, 45% (18 of 40) of the respondents were unsure what they would classify as an acceptable price increase, 15% would accept no cost increase whereas, 27.5%, 7.5%, and 5% of participants would accept a 1–2%, 3–5%, and >5% cost increase, respectively ($P < 0.05$). Alternatively, participants were asked "how much they would raise the price of their

TABLE 7. Farmers' market vendors' main considerations for adopting the three-step wash process and factors that influence their decision to change product prices if they implement the washing method

	Frequency	%	*P*-value of Chi[2]
Main consideration of adopting the three-step wash process (n=38)			< 0.05
Low-cost adoption	26	68.4	
Easy to implement	33	86.8	
Good technical support	5	13.2	
Easy access to information	14	36.8	
High efficacy in lowering microbial risk	13	34.2	
High perceived economic value	11	28.9	
Consumer acceptance of procedure	7	18.4	
High adoption rate among fellow farmers	5	13.2	
Easy to integrate with existing practices	21	55.3	
Standardized procedure	8	21.1	
Government support	4	10.5	
Other written responses:	3	7.9	
Suppose the three-step wash can reduce microbial safety risks by 5%. Adopting the three-step wash may increase your production cost. What is an acceptable range of increase if you do not increase the price of your product? (n=40)			< 0.05
No increase	6	15	
1–2%	11	27.5	
3–5%	3	7.5	
>5%	2	5	
Not sure	18	45	
Suppose applying the three-step wash to reduce Microbial Safety Risks would increase the cost of production by 5%, how much will you increase the price of your products? (n=42)			< 0.05
No increase	1	2.3	
1–2%	5	12.5	
3–5%	5	12.5	
>5%	10	25	
Not sure	21	50	

*Note: Two individuals (5.3%) specified that an additional main consideration for adopting the triple-wash method for them was "low risk of exposure to consumers/workers."

products if the TWM decreased microbial contamination risk by 5% but would also increase production cost by 5%." Again, 50% (21 of 42, $P < 0.05$) were unsure about their choices. However, 25% indicated that they would increase the price of their product by 5% to match the increase in production cost. Results also showed that 12.5% indicated they would increase prices by 1–2 and 3–5% if production costs increased by 5%, and only 2.3% said that they would not increase the price of their produce *(Table 7)*. Our previous cost-benefit analysis determined the annual operating cost of the TWM using H_2O_2-PAA (containing 96 ppm of PAA)is approximately $500 to $2,000 when washing 1,000 to 5,000 butternut squash. However, if the wash tanks are refreshed, an additional 5–220% could be added to the total cost *(16)*. According to a consumer-based survey study, this price increase could be justified because consumers reported they are willing to pay up to 7.5% more for lower food safety risks resulting from the

TABLE 8. Farmers' market vendors' interest in GAP and FSMA training and their preference for training sessions

	Frequency	%	*P*-value of Chi²
Are you interested in attending a three-step wash training in addition to Good Agricultural Practices/Food Safety Modernization Act (GAP/FSMA) (n=49)			< 0.05
Yes	32	65.3	
No	17	34.7	
If yes, which opportunities would you be more interested in? (Please check all that apply) (n=32)			< 0.05
Workshops	10	31.3	
Brochure material	7	21.9	
Website	6	18.8	
Webinar	7	21.9	
Online training video	14	43.8	
Other	1	3.1	
Other than training sessions, what would help you adopt technologies that reduce microbial pathogens? (Choose all that apply) (n=32)			< 0.05
A certification program	8	25	
Free personal consultation	14	43.8	
New state/local regulations	7	21.9	
A consumer education website	15	46.9	
A consumer education program on microbial safety risks to improve consumer awareness	9	28.1	
Other	1	3.1	

*Note: The answer choice "Other" included the written response "A winter seminar."

TWM *(18)*. In the current study, more than half of the survey participants were uncertain about accepting the cost of applying the TWM, which could act as a barrier for local small produce growers considering this new technology. Therefore, determining the cost of the TWM used in real agricultural plant settings is needed to determine the wash methods' economic feasibility.

Training Acceptance and Considerations

The question, "Are you interested in attending a three-step wash training in addition to GAP/FSMA education" resulted in the majority (65.3%; $P < 0.05$) who answered ($n = 49$) responding "Yes." In agreement with our previous antibiotic-resistant survey in the WV local community showing 68% of the survey participants were interested in outreach training opportunities *(23)*. This suggests WV FM vendors are interested in learning food safety practices and regulations to optimize their products and to improve microbial safety. In 2017, WV joined in the Produce Safety Alliance (PSA) led by Cornell University; therefore, prior to this study there were limited GAP training programs for FM personnel and a very limited number of GAP certified FM produce growers in WV. Notably, 32 of the 49 respondents specified the form of training they would prefer. Online training was the preferred method (43.2%) followed by workshops (31.3%), brochure material (21.9%), webinar (21.9%), website (18.8%), and unspecified other choice (3.1%) ($P < 0.05$) *(Table 8)*.

The WV FM vendors were also asked what other programs or information would assist in their adopting new technologies, such as the TWM. The survey results indicated the preferred option was a consumer education website (46.9%), followed by a free personal consultation (43.8%), a consumer education program on microbial safety risks to improve consumer awareness (28.1%), new state/local regulations (21.9%), and a certification program (25%). One individual (3.1%) preferred to have a winter seminar when the harvest season was over *(Table 8)*. Previous FM survey studies *(4, 34, 35, 58)* conducted in other states revealed safe food handling was an issue

TABLE 9. The relationship between the farmers' market vendors' education levels and knowledge of microbial safety of produce sold at farmers' markets

	<12 years of school	High school graduate or GED	Associate degree	Bachelor's Degree	Graduate Degree	Total	*P*-value of Chi²
	n (%)	n (%)	n (%)	n (%)	n (%)	N	
Do you think the following pathogens can be transmitted from fresh fruits and vegetables to humans?							
E. coli							
Yes	2(2.89)	17(24.6)	13(18.8)	22(31.9)	15(21.7)	69(88.5)	< 0.05
No	1(1.1)	3(3.3)	4(44.4)	1(1.1)	0	9(11.5)	
Total per education level (n%=yes)	3(67)	20 (85)	17(23.5)	23(95.8)	15(100)		
Salmonella							
Yes	2(2.9)	16(23.5)	14(20.6)	22(32.4)	14(20.6)	68(84)	< 0.05
No	1(7.6)	4(30.8)	4(30.8)	3(23.1)	1(7.7)	13(16)	
Total per education level (n%=yes)	3(67)	20(80)	18(77.8)	25(88)	15(93.3)		
Listeria monocytogenes							
Yes	2(2.9)	16(18.4)	13(19.4)	22(32.8)	14(20.9)	67(87)	< 0.05
No	1(9.1)	3(27.2)	4(36.4)	2(18.2)	1(9.1)	11(14.3)	
Total per education level (n%=yes)	3(67)	19(84.2)	17(76.5)	24(91.7)	15(93.3)		

and that education targeting local farmers could increase the food safety of products sold at FMs. A FM surveillance study where farmers scored high in food safety knowledge reported that extension educators played a crucial role in providing helpful education to local growers *(2)*.

The relationship between the vendors' education level and knowledge of microbial safety of produce sold at FMs

Surveying vendor knowledge of microbial safety of produce found education was a significant factor. In contrast, a KY FM survey concluded there was no significant relationship between the vendors' education level and knowledge of microbial contamination sources *(40)*. It was observed that vendors from the KY FM study had more experience (6–10 yrs) selling at FMs than the present study's respondents (1–5 yrs), which could be why knowledge levels of contamination differed between studies *(43)*. In the current survey, when asked whether they believed the pathogens *E. coli*, *Salmonella*, and *L. monocytogenes* could be transmitted from vegetables to humans, 88.5, 84, and 87% of participants said "Yes", respectively. Awareness of human to produce pathogen transmission was highest (93–100%) in participants with a graduate level education compared to 67% of participants with 12 years or less of education ($P < 0.05$) *(Table 9)*. Asked to identify potential sources of contaminants, those with a higher education level (college degree) answered this question correctly compared to those with a high school degree, GED, or less education ($P < 0.05$). This is important because while plants provide sub-optimal growth conditions for human pathogens, the pathogens e.g., *Salmonella enterica* and *E. coli* can use different mechanisms such as forming biofilms to attach to more favorable areas on the plants and survive harsh conditions *(69)*.

Shown in *Table 10*, the top recognized sources of contamination by survey participants were storage facilities, display, or preparation (60%) and wild and/or domestic animals (58%). Only 32% of participants thought ice could be a source of microbial contamination. Approximately half of FM vendors thought animal manure, inadequately composed manure, soil, and irrigation water could be sources of cross-contamination. These results are consistent with findings from FM survey studies conducted at East Coast states. Over a quarter of farmers in Georgia, Virginia, and South Carolina waited less than 90 days before applying compost manure to their gardens before harvest *(17)*. This is in opposition with the USDA National Organic Program Rule that states farmers must wait 90 days if the edible portion is not in contact with the soil and up to 120 days if the edible portion of the crop is in contact with the soil before applying manure to a fruit and vegetable garden *(57)*. A study found over 27% of the 226 surveyed farmers

TABLE 10. Relationship between the vendors' education levels and knowledge of potential sources of produce microbial contamination

	<12 years of school	High school graduate or GED	Associate Degree	Bachelor's Degree	Graduate Degree	Total	*P*-value of Chi^2
	n (%)	n (%)	n (%)	n (%)	n (%)	N	
Which of the following do you think are potential sources of contamination on any farm?							
Soil	1(2)	11(22.4)	12(24.4)	17(34.7)	8(16.3)	49	$P < 0.05$
Irrigation water	1(1.9)	12(23.1)	12(23.1)	19(36.5)	8(15.4)	52	$P < 0.05$
Animal manure	1(1.9)	8(15.4)	14(26.9)	18(34.6)	11(21.2)	52	$P < 0.05$
Inadequately composed manure	1(2)	9(18)	10(20)	20(40)	10(20)	50	$P < 0.05$
Wild and/or domestic animals	2(3.4)	10(17.2)	12(20.7)	23(39.7)	11(19)	58	$P < 0.05$
Inadequate worker hygiene	2(3.9)	8(15.7)	11(21.6)	20(39.2)	10(19.6)	51	$P < 0.05$
Transport containers	1(2.1)	10(21.2)	10(21.2)	16(94.1)	10(21.3)	47	$P < 0.05$
Wash and rinse water	1(2.2)	9(20.5)	9(20.5)	17(38.6)	8(18.2)	44	$P < 0.05$
Harvesting equipment	0	10(22.7)	10(22.7)	14(31.8)	10(22.7)	44	$P < 0.05$
Ice	0	5(15.6)	6(18.8)	14(43.8)	7(21.9)	32	$P < 0.05$
Cooling equipment	0	7(20.6)	7(20.6)	13(38.2)	7(20.6)	34	$P < 0.05$
Transport vehicles	0	7(18.4)	7(18.4)	14(36.8)	10(26.3)	38	$P < 0.05$
Improper storage containers (temperature)	0	11(19.6)	10(17.9)	21(38)	14(25)	56	$P < 0.05$
Employees	0	7(18)	9(23)	15(38)	9(23)	40	$P < 0.05$
Cross-contamination in storage, display, or preparation	2(3.3)	14(23.3)	10(16.7)	21(35)	13(21.7)	60	$P < 0.05$

used untested irrigation water to wash produce, 43% did not sanitize surfaces at the farm to process produce, and only 33% cleaned transportation containers between uses *(17)*.

Included in the survey were farming practices recognized by the U.S. FDA as potential sources of contamination, yet only approximately half of participants indicated awareness of these potential sources of contamination *(Table 10)* *(54)*. It is essential that farmers recognize these biological hazards to prevent selling potentially contaminated produce to FM consumers.

Development of the triple wash training at WV local community

The triple-wash survey provided information on small produce growers' perception of microbial risks, and their interest in triple-wash applications. Their feedback and the knowledge gaps revealed by this survey are going to be used to develop an in-person and remote training program. Currently, the authors' team are creating fact sheets tailored toward WV very small fresh produce growers based on the knowledge gap between FSMA regulation and practices identified by this survey. The contents of fact sheets include: 1) Overview of FSMA produce safety rules; 2) Biological soil amendments; 3) Manure and compost management; 4) Agricultural water management; 5) Concept of sanitizing and cleaning; 6) Produce safety at FMs; 7) Strategies for mitigating food safety risks in the local food system; 8) The triple-wash process and its efficacy of reducing food safety risks; 9) Economic feasibility of the triple-wash for various sizes of farmers. We are also editing a 37-page portable handbook of TWM, which includes the concept of the TWM, along with its applications to various types of fresh produce and major microbial pathogens and the dispose the wastewater from TWM.

In addition, we organized a one-day TWM training workshop at our stakeholder's Preston County Workshop Inc. and organized a one-day outreach workshop on post-harvest sanitizing practices with TWM as part of the 2023 West Virginia Small Farm Conference FSMA "Train the trainer" workshop. The authors' team demonstrated using the TWM on butternut squash, cucumbers, spinach and other produce commodities designated by the very small local growers using the stakeholder plant processing tanks. The demo included preparing commercial antimicrobials, measuring temperature, pH, turbidity and antimicrobial concentrations in wash waters using testing strips, TWM process, drying, and storage. We have emphasized that the microbial quality of post-harvest processing water needs to be maintained before and after the triple-wash process. We also conducted the demo of testing coliform and generic *Escherichia coli* using petri-film during the workshop. As of today, there are at least 4 very small produce growers in WV that are applying triple-wash process in their own processing line including Preston County Workshop Inc., Shafer Heritage Farm, Mountain Harvest Farm LLC., and Elmcrest Farm.

LIMITATIONS

Limitations of this study are the results of this study mainly apply to small and very-small growers in WV. The small sample size may also underrepresent FM vendors. Therefore, these results may not be applicable to large-scale or commercial growers. However, this research provided useful information for extension offices and educators on the local scale.

CONCLUSION

In summary, the FM survey revealed a knowledge barrier regarding general food safety and microbial contamination of produce sold at FMs and GAPs amongst local FM vendors and small growers in WV. More than half of vendors were unaware of the TWM, despite local extension office training on TWM for small growers in the area. Further, despite efforts by regional extension offices, food safety remains an issue for local FM produce vendors. These preliminary survey results may support the need to restructure and expand current food safety training to include education on GAPs and the TWM for small and very-small produce growers. Particularly, since most respondents indicated they would be willing to attend such training, specifically if offered online or in an in-person workshop. However, more participants and more specific training questions are needed to determine if the results from this survey truly represent the FM vendor population. Understanding FM vendors' perceptions and current wash methods allows local state government agencies to make better informed decisions regarding food safety policies to ensure produce safety. Using the information from the findings of this study, the authors' team plans to work closely with the WV SFC to develop outreach activities on training WV very small to small produce growers on applying the TWM. So far, this training will include conducting in-person plant onsite workshops or remote training courses of the TWM as a supplement for FSMA's "train the trainer" workshop. Also, a handbook on proper triple wash applications on produce will be written and disseminated to these local growers. The U.S. Department of Agriculture, National Institute of Food and Agriculture, and Food Safety Outreach Program will support these outreach activities.

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