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Assessing Physical Attributes Associated with Implementation of Risk Management Practices among Small Strawberry Farms

ABSTRACT

Fresh strawberries are susceptible to contamination with foodborne pathogens, illustrating the importance of on-farm risk management practices (RMP). Understanding context is necessary for successful implementation of RMP, highlighting the importance of characterizing physical attributes (PA) associated with RMP. We determined the PA associated with implementation of eight RMP on 20 small (≤ 2 acres; 8,094 m^2) strawberry farms in the southeastern United States. Descriptive statistics were performed to determine frequency of PA across farms. PA scores, presence or absence of observed PA expressed as a percentage, were calculated for each of the eight RMP. All 20 (100%) farms used plasticulture to grow strawberries. All (100%) used drip irrigation systems, and 19 (95%) had an adequate number of bathrooms and handwashing stations. Nearly all (95%) did not have a body fluid spill kit. Sixteen (80%) farms used groundwater or surface water for irrigation, with five (31%) treating the water and eight (50%) testing the microbiological quality of irrigation water. PA scores ranged from 55 to 90%, with the highest (90%) for animal control and the lowest (55%) for food safety signage. These findings can inform strawberry-specific safety interventions aimed to increase RMP implementation. More broadly, this represents another approach to informing commodity-specific training needs.

INTRODUCTION

Strawberries (*Fragaria × ananassa*), the third largest noncitrus fruit crop in the United States, have an estimated value of US$2.5 billion *(69)*. According to the 2017 U.S. Census of Agriculture, 8,964 strawberry farms were spread over 60,162 acres (243.5 km^2) in the United States *(67)*. In 2018, most strawberries by volume (2.9 billion lb; 1,315,417,873 kg) were harvested in California (90%), followed by Florida (9%), with 1% collectively harvested in all other states *(70)*.

Strawberries, as well as other berries, green onions, melons, tomatoes, and sprouted seeds are classified as level 2 priorities, the second-highest concern group for microbial contamination *(23)*. The susceptibility of fresh

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strawberries to contamination is evident by the number of reported foodborne disease outbreaks *(44, 49)*. Between 1997 and 2017, 32 strawberry-related outbreaks were reported, sickening 933 people in the United States *(11)*. Pathogens associated with these outbreaks included Shiga toxin-producing *Escherichia coli*, nontyphoidal *Salmonella*, *cyclospora*, norovirus, and hepatitis A virus *(11)*.

Strawberries are susceptible to microbial contamination for several reasons: they are hand harvested, not washed before packing (i.e., if intended for the fresh market), and grown close to the soil *(3, 16, 33, 45, 49, 58, 60)*. In addition, the natural openings on the external surfaces provide niches for pathogens to hide, making pathogens difficult to remove by washing before eating *(18, 58, 76, 77)*. Strawberries can also become contaminated through contact with animals, agricultural water, biological soil amendments of animal origin (BSAAO), as well as contaminated equipment, tools, and buildings at the farm level *(75)*. Importantly, strawberries are often eaten raw *(71)*, with no kill step to eliminate pathogens before consumption. All these reasons illustrate the importance of proper implementation of risk management practices (RMP).

Improving the safety of fresh produce, including strawberries, is a priority of the Food Safety Modernization Act standards for the growing, harvesting, packing, and holding of produce for human consumption, commonly referred to as the Produce Safety Rule (PSR) *(75)*. The Produce Safety Alliance, the only U.S. Food and Drug Administration-recognized grower training program, delivers training aimed to increase compliance with the PSR *(58)*. At present, training is not mandatory under the PSR for very small produce farms, defined as farms earning less than US$25,000 in annual sales (3-year average, adjusted for inflation), as well as other qualified exempt farms *(75)*. In 2017, 89% of U.S. strawberry farms were less than 5 acres (20,234 m^2), and 66% were less than 1 acre (4,047 m^2) *(67)*. The average strawberry farm size in 36 U.S. states is less than 2 acres (8,094 m^2), which is also the average for 8 (62%) of 13 southeastern (SE) states *(67)*. In 2017, the U.S. average value of utilized production of strawberries (except California and Florida) was US$21,572 per 2 acres (8,094 m^2) *(70)*; hence, many strawberry farms were exempt from the mandatory Produce Safety Alliance grower training.

Even though researchers, produce industry members, and government personnel have identified and communicate RMP through training, produce-associated outbreaks continue to occur *(10)*. One explanation might be that small farms (i.e., those that are exempt) are less likely to implement RMP *(1, 5, 50)*. Consequently, new approaches are needed to improve implementation of RMP on small farms, including strawberry farms. Implementation science methodology could be used to inform training aimed to improve on-farm implementation of RMP. One underlying principle in implementation science is that understanding context, such as availability of tools and adequate infrastructure, is necessary for successful implementation of an intervention *(48)*, highlighting the importance of characterizing physical attributes (PA) associated with RMP. To date, most published studies conducted with produce growers, including strawberry producers, have focused on directly and indirectly assessing RMP and not PA associated with RMP *(1, 39, 47, 59)*. A published review examined the relationship between environmental attributes, including PA, and RMP on produce farms *(41)*. To the best of our knowledge, no studies have specifically focused on characterizing PA associated with the implementation of RMP on strawberry farms.

This descriptive study aimed to determine the PA associated with implementation of RMP of a convenience sample of 20 small strawberry farms in the SE United States. Within the context of this study, we defined small farms as those that are ≤ 2 acres (8,094 m^2). These findings can inform strawberry-specific safety interventions aimed to increase RMP implementation.

MATERIALS AND METHODS

Ethics statement

The study protocol was reviewed by the Clemson University Institutional Review Board (2019-375) and determined to be exempt. An informed consent form with a description of the research background, procedures, risks, benefits, and confidentiality was provided to growers or on-farm representatives, and consent was obtained before site visits were conducted. Farm identification information (e.g., farm name, contact person name, farm address, phone number, and e-mail address) was also collected. All data were kept confidential and were only accessible to research team members.

Sample selection and recruitment of data collectors

Our target population was a convenience sample of small strawberry farms, defined as ≤ 2 acres (8,094 m^2), across 13 SE states: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. Two or more small strawberry farms from each SE state were recruited.

Fourteen data collectors who work in horticulture and food safety were recruited from 10 of 13 SE states. Data collectors were expected to (i) recruit at least two small strawberry farms in the state and (ii) conduct on-farm assessments on those farms. A 30-min training Webinar about data collection procedures was conducted before data collection began. Of the 14 recruited data collectors, 10 completed on-farm assessments. Four data collectors did not complete the on-farm assessments due to individual state COVID-19 restrictions regarding university-sponsored research activities.

Instrument development

Site visits were conducted by using an environmental assessment (EA) checklist *(Supplemental Material for the*

EA checklist), developed by the research team. The checklist was based on the U.S. Department of Agriculture (USDA) Harmonized GAP standards and the Produce Safety Alliance grower training curriculum *(58, 68)*. It included items in eight categories: (i) farm information; (ii) worker health and hygiene; (iii) agricultural water; (iv) animal control; (v) BSAAO; (vi) harvesting and packing; (vii) storage and transportation; and (viii) miscellaneous. A postharvest addendum checklist *(Supplemental Material for the postharvest addendum checklist)* was also created to assess PA on farms engaged in postharvest practices. This checklist was completed if growers responded to selected items in the EA checklist. In the postharvest addendum checklist, there were three assessment postharvest categories: (i) handling and sanitization; (ii) processing; and (iii) storage and transportation. Both checklists were reviewed by two produce safety experts for relevance and clarity of all items, and revisions were made on the basis of feedback. Both checklists were then pilot tested on two Florida strawberry farms. A coding manual *(Supplemental Material for Coding Manual)* was also developed to define the coding process of categorical data into numeric values.

Data collection

On-farm assessments were conducted between June 2020 and October 2020. Each farm was assigned a unique identification number. Data collection started with the EA checklist. Data were recorded by checking "yes" if PA were present and "no" if PA were absent. Additional details relevant to items in each category were recorded in the "comments" or "additional comments" sections of the checklist. A map of the farm layout was also drawn, including location of all farm features, such as strawberry production fields, potential contamination sources (e.g., BSSAO piles, animal enclosures), and farm structures (e.g., agriculture water well, postharvest facility, bathrooms, handwashing stations [HWS], and fences). A farm layout for 18 farms was drawn on a downloadable 0.25-cm grid sheet (https://willcarletonacademy.com/wp-content/uploads/2020/04/small-graph-paper.pdf), and the layout for six farms was prepared by using Google Maps *(29)*; both methods were used for 4 (20%) of 20 farms. The shortest and longest distances between toilets and/or HWS and produce handling areas were measured by using a Zozen collapsible measuring wheel (ACOOJ, Hebei SNDAS Survey and Draw, Hebeisheng, China). The shortest distances between contamination sources and produce handling areas and water sources were also measured by using the same Zozen collapsible measuring wheel. The PSR currently does not state how far contamination sources (e.g., animal enclosures and BSAAO storage areas) should be from production fields or agricultural water sources; therefore, alternative sources were used to identify safe distances. According to the Centers for Disease Control and Prevention, a drinking water well should be located a minimum of 50 ft (15.2 m) and 250 ft (76.2 m) from a livestock yard and manure pile, respectively, to minimize potential contamination *(12)*. In this study, we defined a safe distance from strawberry production fields and agricultural water sources as >50 ft (15.2 m) from an animal enclosure and >250 ft (76.2 m) from the BSAAO storage area. Data collectors completed a data collection form checklist to ensure all steps of the data collection process were finalized before leaving the farm. The tools required for data collection were provided to data collectors by the research team to better ensure consistency of assessments.

Data management and analysis

All data were entered into a Microsoft Excel spreadsheet (Microsoft Corporation, Redmond, WA) and coded according to the coding manual. All entered data were checked for accuracy by one research team member. Descriptive statistics on all variables were performed to determine frequency (i.e., presence) of PA by using JMP software (version 14.1; SAS Institute Inc., Cary, NC). The PA score was calculated on the basis of the presence or absence of observed PA for each checklist category. A value of 1 was assigned, if the PA was present, and a value of 0 was given, if the PA was not present. To calculate the PA score for each category, the number of PA present was divided by the total possible for each category. This value was expressed as a percentage. Selected farm PA, not having an impact on RMP implementation, were not used to calculate PA scores. For example, the availability of a harvest cart on a farm to harvest strawberries was not used to calculate the PA scores, because its purpose is to increase worker productivity, rather than decrease food safety risks *(4)*. Practices reported by growers to implement RMP were also not used to calculate the PA scores (e.g., collecting water samples for testing), because our aim was to report PA associated with implementation of RMP, not actual implementation of a specific practice.

RESULTS

A total of 20 farms from 10 SE states (Alabama, Arkansas, Georgia, Kentucky, Mississippi, North Carolina, Oklahoma, Tennessee, Texas, and Virginia) participated in the study. These 20 farms included 2 farms each from Alabama, Arkansas, Georgia, Kentucky, Oklahoma, Tennessee, Texas, and Virginia, 3 farms from North Carolina, and 1 farm from Mississippi. The assessment data from those 20 farms were used for the analysis. Responses for each item varied, as all items in the EA checklist and postharvest addendum checklist were not applicable to all farms or were not recorded. For the latter, although this could have been due to the absence of the PA, the study team did not assume this; thus, in those instances, data were coded as missing.

Farm characteristics

Farm characteristics, including farm size, worker number, and worker type are in *Table 1*. The average acreage was

1.2 acres (4,856.2 m^2), ranging from 0.1 to 2 acres (405 to 8,094 m^2). Crops, other than strawberries, such as tomatoes, squash, pumpkin, and apples, were grown on 95% of farms. The plasticulture method was used by all farms for strawberry production, with a greenhouse system used by three farms, and matted row, high tunnel, and low tunnel methods used by one farm each. The U-pick operations were common on most (70%, *n* = 14) farms, and further processing of strawberries was conducted on four farms.

PA associated with implementation of worker hygiene practices

Nineteen (95%) farms had bathrooms with 18 (95%) of the 19 located within 0.25 mi (0.40 km) of the working area. All were adequate (one toilet per 20 workers) *(72)*, having visibly clean toilets and appropriate toiletry resources, such as toilet paper (100%, *n* = 19), trash receptacles (89%, *n* = 17), and potable running water (84%, *n* = 16). Nearly half (47%, *n* = 9) had workers use toilets in the grower's home (in-house toilets) *(Table 2)*.

Nearly all (95%; *n* = 19) of the 20 farms had HWS located within 0.25 mi (0.40 km) of the working area. All were adequate (one HWS per 20 workers) *(72)*. On over half (58%, *n* = 11) of the farms, HWS were attached to the bathroom. All (100%, *n* = 19) had necessary tools to wash hands (e.g., potable running water and soap). The presence of single-use paper towels or hand dryers were reported on 18 farms, and all (100%) had single-use paper towels or hand dryers *(Table 2)*. Additional clothing (e.g., gloves, face masks, and boots or shoe covers) were provided to workers on 14 (70%) farms, with gloves the most (93%, *n* = 13) commonly provided item *(Table 2)*. Only one farm (5%) had a body fluid spill kit.

PA associated with implementation of agricultural water practices

All 20 (100%) strawberry farms used a drip irrigation system, and 17 (89%) had backflow devices installed on water distribution systems. Most farms used groundwater, followed by municipal water and surface water as the preharvest water source *(Fig. 1)*. The majority (60%, *n* = 12) used only one preharvest water source, while the remaining eight (40%) used two water sources. Only a few treated groundwater or surface water before irrigation (31%, *n* = 5), frost protection (33%, *n* = 1), pesticide application (18%, *n* = 2), fertigation (25%, *n* = 4), and handwashing (groundwater; 27%, *n* = 3) *(Table 3)*. The most common water treatment method was filtration (e.g., sand filters, screen filters) *(Table 3)*. Additionally, half (50%, *n* = 8) of the 16 farms that used groundwater or surface water did not test the water for microbiological quality.

PA associated with implementation of animal control practices

Of the 20 farms, nearly half (45%, *n* = 9) raised livestock; none raised working animals. On six (67%) of these nine farms, livestock enclosures were located at a safe distance (>50 ft or 15.24 m) from production fields, while livestock enclosures on the remaining three (33%) farms were not. Distances between livestock enclosures and water sources were reported on only six farms (67%), and the water sources for all six (100%) were at a safe distance. Nearly all (90%, *n* = 18) had one or more preventive measures for animal intrusion, with fences being used on all 18 farms (100%) *(Table 2)*. Most farms had no indicators of domesticated animals (95%, *n* = 18), such as pets, livestock, and working animals, or wild animals (63%, *n* = 12). Indications of animal intrusion were documented for a few farms, including foot tracks (40%, *n* = 8), feces (15%, *n* = 3), and trampling (15%, *n* = 3) *(Table 2)*.

PA associated with implementation of BSAAO practices

Only 4 (20%) of 20 farms used BSAAO for strawberry production. Of these four farms, three (75%) used a safe BSAAO source *(Table 2)*. All four (100%) obtained BSAAO from a supplier, rather than producing it on farm. Three (75%) farms had a separate vehicle for BSAAO transportation, and two (50%) had a designated storage space for BSAAO handling tools. BSAAO were stored on three (75%) farms with established contamination preventive measures *(Table 2)*. However, BSAAO storage areas were not located at a safe distance (>250 ft or 76.2 m) from strawberry production fields or water sources on two of four (50%) farms.

PA associated with implementation of harvesting and packing practices

Less than half (40%, *n* = 8) of the 20 farms had harvest carts for strawberry harvesting *(Table 2)*. Of those eight farms, harvest carts were cleaned at seven (88%) of the farms and sanitized at two (25%) farms *(Table 2)*. Of the 20 farms, the most (95%, *n* = 19) common harvest containers were buckets or pails, followed by boxes or bins (35%, *n* = 7), and clamshells (25%, *n* = 5). The strawberry packing method was reported on 17 farms. Of these 17 farms, most (76%, *n* = 13) used the field packing method, and 6 (35%) used an on-farm packing facility designated for strawberry packing.

PA associated with implementation of storage, transportation, and miscellaneous attributes

Nine (45%) of 20 farms stored packed strawberries on site. In addition, less than half (45%, *n* = 9) transported packed strawberries, and only five (56%) of these nine farms used a separate transport vehicle for produce transportation. Food safety signage communicating RMP, such as proper handwashing signage and visitor policy posters, was posted on over half (55%, *n* = 11) of the 20 farms. Of these, the type of food safety signage was reported on nine (82%) farms, and signage related to proper handwashing, proper strawberry handling, and visitor policies were observed on those nine farms.

TABLE 1. Characteristics of small strawberry farms in 10 states in the SE United States (n = 20)

Item	Frequency of farms (n)	%
Total farm size		
0 to 50 acres (0 to 0.2 km^2)	8	40
50 to 100 acres (0.2 to 0.4 km^2)	2	10
100 to 150 acres (0.4 to 0.61 km^2)	2	10
150 to 200 acres (0.61 to 0.81 km^2)	0	0
200 to 250 acres (0.81 to 1 km^2)	2	10
250 to 300 acres (1 to 1.2 km^2)	1	5
>300 acres (1.2 km^2)	5	25
Item	**Frequency of farms (n)**	**%**
Farm size allocated to grow produce		
0 to 5 acres (0 to 20,234 m^2)	10	50
5 to 10 acres (20,234 to 40,469 m^2)	3	15
10 to 15 acres (40,469 to 60,703 m^2)	0	0
15 to 20 acres (60,703 to 80,937 m^2)	0	0
20 to 25 acres (80,937 to 101,171 m^2)	0	0
>25 acres (101,171 m^2)	7	35
Total no. of workers		
1 to 5 workers	9	45
6 to 10 workers	5	25
11 to 15 workers	4	2
16 to 20 workers	1	5
>20 workers	1	5
Types of part-time workers[a]		
Seasonal	11	61
H-2A	5	28
Contract	1	6
Family	1	6
Item	**Frequency of farms (n)**	**%**
Summer helpers (local kids)	1	6

[a]Type of part-time workers was not recorded for two farms; thus, sample size is n = 18.

TABLE 2. PA associated with implementation of preharvest RMP

Category	Item	No. of farms the data were reported[a, b]	No. of farms with PA present	% Farms with PA present
Worker hygiene	**PA**			
	Availability of protective clothing			
	Harvesting	19	13	68
	Packing[c]	16	10	63
	BSAAO handling	3	3	100
	Protective clothing type[d]			
	Gloves	14	13	93
	Face mask	14	10	71
	Overalls	14	2	14
	Apron	14	4	29
	Boots/shoe cover	14	5	36
	Bathroom			
	Availability of toilets	20	19	95
	Toilet types			
	Portable	19	6	32
	In house[e]	19	9	47
	Permanent[f]	19	7	37
	Unlocked portable toilets	6	6	100
	Unlocked bathrooms	19	19	100
	Toiletry resources			
	Toilet paper	19	19	100
	Trash receptacles	19	17	89
	Wash water	19	16	84
	Conveniently located bathrooms	19	18	95
	Clean bathrooms			
	Toilet	19	19	100
	Sink	18	17	94
	Wall	19	18	95
	HWS			
	Availability of HWS	20	19	95
	Resources in HWS			
	Potable running water	19	19	100
	Soap	19	19	100
	Hand sanitizer	19	14	74
	Single-use paper towels or hand dryer	18	18	100
	Conveniently located HWS	19	19	100
	Clean HWS	14	14	100
	Body fluid kit	20	1	5

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TABLE 2. PA associated with implementation of preharvest RMP (cont.)

Category	Item	No. of farms the data were reported[a, b]	No. of farms with PA present	% Farms with PA present
Agricultural water	**PA**			
	Drip irrigation system	20	20	100
	Backflow devices	19	17	89
	Features of PA			
	Collect water for testing	16	11	69
	Water tested for microbial quality	16	8	50
Animal control	**PA**			
	Animal preventative measures			
	Fencing	20	18	90
	Netting	20	0	0
	Decoys	20	5	25
	Noise deterrent	20	4	20
	Tactile repellent	20	0	0
	Features of PA			
	Animal access			
	Observation of animals on farm			
	Domesticated animals	19	1	5
	Wild animals	19	7	37
	Signs of animal intrusion			
	Foot tracks	20	8	40
	Animal feces	20	3	15
	Trampling	20	3	15
	Visual	20	3	15
BSAAO handling	**PA**			
	Types of BSAAO			
	Stabilized/treated compost	4	2	50
	Treated manure	4	1	25
	Aged manure	4	1	25
	Separate vehicle to transport BSAAO	4	3	75
	Designated storage space for handling tools	4	2	50
	Contamination preventative measures for BSAAO storage			
	Covered area	3	2	67
	Covered piles	3	0	0
	Built berms	3	0	0
	Away from high foot traffic areas	3	3	100

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TABLE 2. PA associated with implementation of preharvest RMP (cont.)				
Category	Item	No. of farms the data were reported[a, b]	No. of farms with PA present	% Farms with PA present
BSAAO handling	**PA**			
	Contamination preventative measures for BSAAO storage			
	Fencing around the pile	3	0	0
	Stored in a sealed bag	3	1	33
	Stored in downhill	3	1	33
	Stored in bags	3	1	33
	Features of PA			
	Use of BSAAO	20	4	20
	Store BSAAO on the farm	4	3	75
Harvesting and packing	PA			
	Harvest cart	20	8	40
	Clean cart bed	7	7	100
	Covered cart bed	8	3	38
	Harvest container type			
	Clamshell	20	5	25
	Bucket/pail	20	19	95
	Box/bin	20	7	35
	Features of PA			
	Cleaning and sanitizing of harvest cart			
	Clean	8	7	88
	Sanitize	8	2	25
	Cleaning frequency of harvest cart			
	Daily	8	4	50
	Weekly	8	1	13
	As needed	8	3	38
	Strawberry packing method			
	Field packing	17	13	76
	Packing facility	17	6	35

[a]Sample size for each item varied, as all items in the checklists were not applicable or present on all farms; some data could not be assessed due to the strawberry off-season.

[b]Not all observations were recorded for each PA; therefore, if the presence of a given PA was not recorded, it cannot be assumed that the PA were not present.

[c]Protective clothing can be used either for field packing or packing in a packing facility.

[d]Fourteen farms provided protective clothing for harvesting, packing, or BSAAO handling. Data collectors were allowed to indicate all protective clothing types provided by farms during harvesting, packing, and BSAAO handling.

[e]In-house toilets defined as toilets in grower or farm owner's home used as worker toilets.

[f]Permanent toilets defined as toilets permanently fixed on the farm ground.

TABLE 3. Type of water treatment methods used for preharvest water before application (n = 20)

Preharvest water use	Sample size[a]		No. of farms treated with preharvest water		Preharvest water treatment method and no. of farms applied[b]			
					Chemical		Filtration	
	No.	%	No.	%	No.	%	No.	%
Irrigation	16	80	5	31	0	0	5	100
Frost protection	3	75	1	33	0	0	1	100
Pesticide application	11	61	2	18	1	50	2	100
Fertigation	16	80	4	25	0	0	4	100
Handwashing	11	55	3	27	1	33	3	100

[a]Number of farms that used groundwater or surface water.
[b]Both chemical and filtration as a pretreatment method were applied by some farms.

PA associated with postharvest practices

Six (35%) farms packed strawberries in on-farm packing facilities, with most (83%, n = 5) packing facilities closed to the outside environment (*Table 4*). Of these 6 farms, most had the PA to implement sanitation practices in packing facilities. For example, 5 (83%) farms used microbiologically tested water for cleaning and sanitization of food-contact surfaces. Use of sanitizers on food-contact surfaces and non food-contact surfaces in packing facilities was reported on six and five farms. Use of disinfectants on food-contact and non food-contact surfaces in packing facilities was reported on five (83%) farms. Most (60%, n = 3) used disinfectant on food-contact surfaces, whereas only two (40%) used disinfectants on non food-contact surfaces. Moreover, only half (50%, n = 3) had a written standard operating procedure for cleaning and sanitization. Packing facilities on six farms implemented one or more pest control measures, with the most common (80%, n = 4) being closing the doors (*Table 4*).

Packaging materials were stored on 16 (80%) of 20 farms. Of that (n = 16), characteristics of packaging materials storage were reported on 13 (81%) farms, and all (100%) stored packaging materials in a covered and clean place, with 11 (85%) storing packaging materials off the floor. Nine (45%) farms stored packed strawberries, with contamination preventive measures reported on seven (78%) farms. Of those (n = 7) farms, all (100%) stored packed strawberries off the floor and in a clean area. Furthermore, all had one or more pest control measures, such as closing open doors (100%, n = 7), traps (43%, n = 3), and chemical usage (14%, n = 1) (*Table 4*). Cleanliness of transport vehicles was reported on 4 (80%) farms that used a separate vehicle to transport strawberries (n = 5), with all (100%, n = 4) being reported as visibly clean. Strawberry processing activities were conducted on 4 (20%) of the 20 farms. The most common processing activities were washing (75%, n = 3), cooling (75%, n = 3), and slicing (75%, n = 3) (*Fig. 2*).

PA scores for RMP implementation

The PA scores for each RMP, worker hygiene, agricultural water, animal control, BSAAO, harvesting and packing, storage and transportation, miscellaneous attributes, and postharvest practices are in *Table 5*. The PA scores for all eight RMP ranged from 55.0 to 90.0%. The highest PA score (90%) was for animal control, and the lowest was for miscellaneous attributes (55%), due to no food safety signage posted on some farms. The next lowest PA score was for strawberry storage and transportation (55.6%).

DISCUSSION

Understanding context, specifically available PA, is necessary for the successful implementation of an RMP. The aim of this study was to determine the presence or absence of PA associated with implementation of RMP on small strawberry farms (≤ 2 acres; 8,094 m^2) in the SE United States. This is the first study of this type used to characterize PA on strawberry farms.

PA associated with implementation of RMP

Most farms had the PA to enable implementation of RMP with two key exceptions. Only 1 (5%) of 20 farms had a body fluid spill kit, presumably because it is not required by the PSR (*75*). Even though to date, no reported outbreaks have been attributed to a body fluid contamination event on a farm, we assert having such a kit needs to be emphasized, particularly given the intent of the PSR is to focus on preventive measures, and body fluids are well-known sources of microbi-

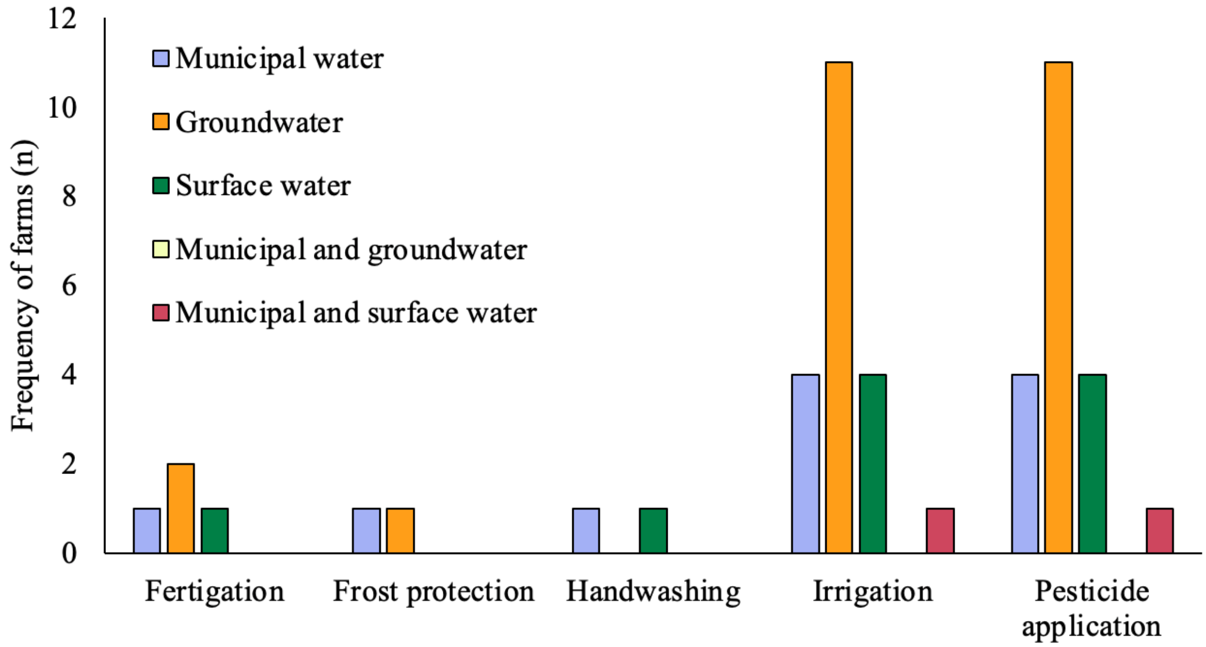

FIGURE 1. Distribution of type of water source used by preharvest strawberry production activities (*n* =20). Frequencies are based on 20 farms for irrigation, fertigation (application of fertilizer materials through the irrigation system), and handwashing, with 18 farms for pesticide application and 4 farms for frost protection.

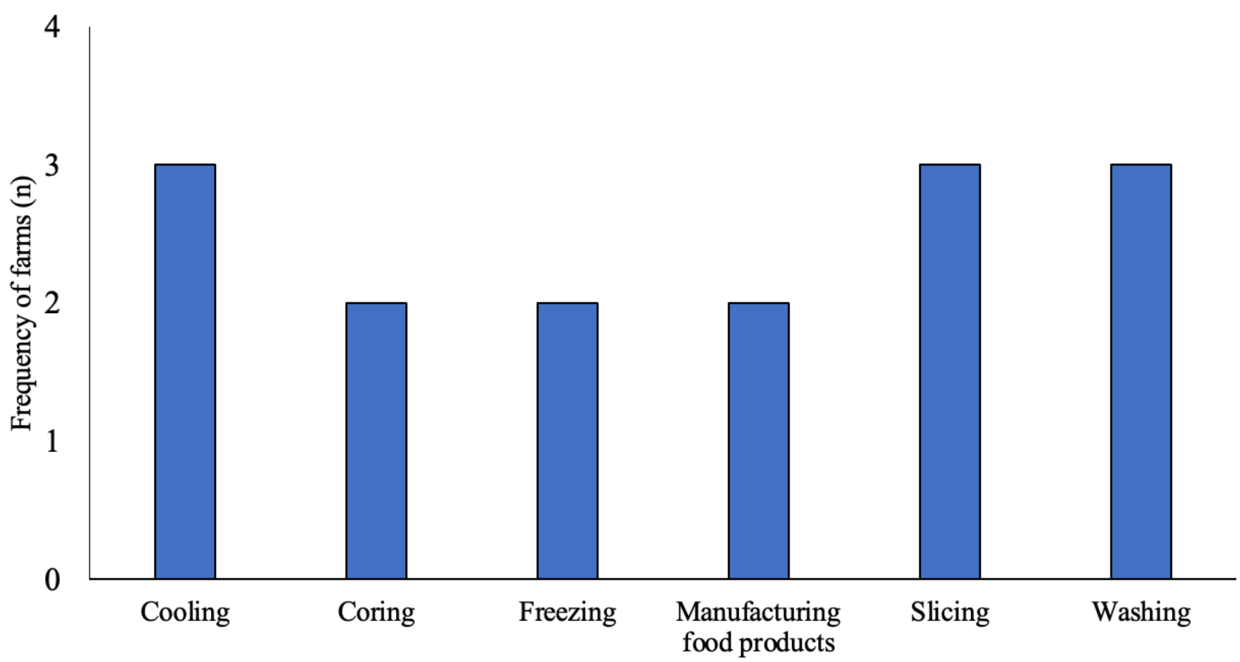

FIGURE 2. Strawberry processing methods (*n* = 20). Frequencies are based on four farms that engaged in strawberry processing.

TABLE 4. PA associated with postharvest practices

Item		No. of farms with data reported[a, b]	No. of farms with PA present	% Farms with PA present
	PA			
	Microbiologically tested water	6	5	83
	Use of sanitizers			
	Food-contact surfaces	6	6	100
	Non food-contact surfaces	5	5	100
	Use of disinfectant			
	Food-contact surfaces	5	3	60
	Non food-contact surfaces	5	2	40
	Written standard operating procedures			
	Cleaning	6	3	50
	Sanitizing	6	3	50
	Pest control measures: packing facility			
	Netting open door	6	0	0
	Closing open door	5	4	80
	Tactile repellent	5	1	20
	Traps	6	3	50
	Chemicals	6	1	17
Strawberry packing facility	Type of packing facility			
	Closed to the environment	6	5	83
	Partially enclosed to the environment	6	1	17
	Clean food-contact surface			
	Sorting table	5	5	100
	Packing table	5	5	100
	Attributes of packaging material storage			
	Covered	13	13	100
	Clean	13	13	100
	Off floor	13	11	85
	Designated storage space			
	Cleaning chemicals	6	6	100
	Cleaning tools	6	6	100
	Trash receptacles			
	Indoor	6	6	100
	Outdoor	6	5	83
	Lidded trash receptacles			
	Indoor	6	4	67
	Outdoor	6	3	50

Continued on next page.

TABLE 4. PA associated with postharvest practices (cont.)

Item		No. of farms with data reported[a, b]	No. of farms with PA present	% Farms with PA present
Strawberry packing facility	PA			
	Pest control measures: strawberry storage			
	Netting open door	7	0	0
	Closing open door	7	7	100
	Tactile repellent	7	0	0
	Noise deterrent	7	0	0
	Traps	7	3	43
	Chemicals	7	1	14
	Clean produce transportation vehicle	4	4	100

[a]Sample size for each item varied, as all items in the checklists were not applicable or present on all farms; some items could not be assessed due to the strawberry off-season.

[b]Not all observations were recorded for each PA; therefore, if the presence of a given PA was not recorded, it cannot be assumed that the PA were not present.

TABLE 5. Summary of PA scores calculated for PA to implement RMP

Category	Maximum possible score[a]	Total score across all farms[b]	% Total scores
Worker hygiene	344	303	88
Agricultural water[c]	121	85	70
Animal control	20	18	90
BSAAO handling	15	11	73
Harvesting and packing	15	10	67
Storage and transportation	9	5	56
Miscellaneous	20	11	55
Postharvest practices	155	135	87

[a]Total sum of scores received for a category if all PA relevant to each item of that category are present to implement RMP across all farms where data were reported.

[b]Total sum of scores received for PA that are actually present in each item of a category to implement RMP across all farms where data were reported.

[c]Presence of a safe water source was considered to calculate PA scores. A safe water source is defined as municipal water, groundwater, or surface water that is tested for microbial quality at least annually.

al contaminants *(9, 14, 22, 43, 53)*. Moreover, other segments of the food chain are required to have spill kits (e.g., processing, retail, and foodservice), so it is important that similar requirements be addressed across the entire food chain.

The U-pick customers did not have access to toilets (*n* = 2) and HWS (*n* = 1) on some farms, so customers could choose to defecate or urinate in the field, possibly directly contaminating strawberries *(30)* or increasing pathogen spread by unclean hands because they do not have access to HWS *(31, 34, 66)*. Not surprisingly, farm workers were reported to increase handwash frequency if HWS and tools needed to wash hands were readily available *(52, 56, 62)*. These latter study findings could, with caution, also be applied to U-pick customers.

On some farms, workers were also provided additional apparel, such as gloves (*n* = 13) and face masks (*n* = 10), with the latter presumably due to the COVID-19 pandemic, though additional clarifying information was not collected during the on-farm assessments. Properly constructed and used gloves can act as a barrier between hands and produce *(46)* but are currently not required by the PSR *(75)*.

Potentially high-risk water sources, such as groundwater and surface water, without subsequent treatment or testing, were also observed. Compromised groundwater systems *(2, 6, 8, 24, 25, 35, 37, 63)* and contaminated irrigation waters *(27, 28, 32)* are well-documented sources of pathogen contamination *(28)*. To determine if water sources are contaminated, one needs to routinely test agricultural waters, and if problems are detected, the water needs to be subsequently treated. The estimated average annual water testing and treatment costs for a small-scale produce grower are estimated to be US$206 and US$1,189, respectively *(5)*. However, some growers might choose not to test or treat their water because of this cost. Lack of knowledge about water quality could also lead to the use of high-risk water sources. For example, a study of 246 growers in Minnesota showed that many (66%) agreed that the source of irrigation waters was not a source of foodborne pathogens *(36)*. In another study, only 14% of 31 produce growers were concerned about irrigation water quality on fresh produce safety *(51)*. Pivarnik et al. *(57)* reported that well water is generally considered by over half (56%) of 301 growers to be the safest source for irrigation. Chen et al. *(15)* reported handling of agricultural water (i.e., water application, sampling, testing) was one of the least understood food safety topics by growers. These studies illustrate the need for further training about agricultural water source risks, safe application, testing, and treatment, as grower knowledge and perceptions about it as a source of contamination is somewhat limited and highly variable within the produce grower population. Notably, all growers in our study used drip irrigation systems for strawberry production, minimizing contamination of strawberries even though some used high-risk water sources for other applications, such as frost protection, pesticide application, fertigation, and handwashing.

Production fields and water sources on some farms were not located at a safe distance from potential contamination sources (e.g., animal enclosures and BSAAO storages). Due to the proximity, pathogens from these sources can be spread during runoff, such as during heavy rainfall and snow melt, possibly contaminating strawberry production fields, as well as agricultural water sources *(13, 27, 73)*. Growers need to be able to identify potential contamination sources on the farm environment that can influence the contamination of strawberry fields or water sources by human pathogens.

Most farms in our study had animal preventive measures present (e.g., fences, decoys, noise deterrents), which was similar to findings from other studies, including one specific to strawberry growers in the SE United States *(5, 41, 78)*. However, animal intrusion, such as animal feces and trampling in production fields, was reported on some farms, possibly due to the use of ineffective preventive measures. Strawberries can become contaminated by various animals (e.g., aerial animals, burrowing animals, terrestrial animals), their feces, as well as through intermediate vectors (e.g., insects and vermin) *(19, 21, 26, 40, 44)*. To effectively use animal preventive measures, it is necessary to first identify what types of animals enter the farm, so the grower can use an appropriate measure for the animal type. For example, fences are effective against terrestrial animals, such as deer, but ineffective against aerial and burrowing animals *(51)*. Animals might also access production fields when preventive measures, such as fences, are not maintained or when livestock or pets are allowed in production areas. For example, 51.8% of 226 produce growers indicated that livestock and pets had access to production fields *(34)*. Also, a study of 160 fresh produce growers showed that 25% did not identify wild and/or domestic animals walking through farms as a source of contamination *(61)*, indicating that animals were allowed in the production area.

Nearly half of the farms did not have food safety signage, most likely because it is not required by the PSR *(75)*. Growers may assume customers are aware of applicable on-farm food safety practices *(20)*. Pivarnik et al. *(57)* reported 91% of 301 produce growers stated U-pick customers should be aware of hygienic practices, such as handwashing, prior to picking. Posting food safety signage is an inexpensive method to communicate with customers. In fact, one study reported many growers were interested in posters to reinforce RMP *(17)*.

Regarding postharvest practices, some farms did not have the PA needed to properly implement RMP *(Table 4)*. This could be possibly due to the lack of awareness among growers about RMP related to postharvest practices. For example, less than 50% of 210 vegetable growers surveyed strongly agreed that storage containers, transportation equipment, processing equipment, and postharvest wash water could be potential contamination sources *(38)*. A survey study conducted with small fresh produce growers (>1 to 2 acres; 4,047 to

8,094 m²) found that only 47% (n = 15) of growers managed packing facility sanitation and transportation *(61)*. Sinkel et al. *(61)* also reported nearly half of growers (n = 160) identified storage, display, or preparation (51%), transport vehicles (45%), refrigeration or cooling (28%), produce wash and rinse water (36%), and transport containers (52%) as possible sources of cross-contamination. Costs associated with purchasing and maintaining PA may contribute to the absence of some PA related to postharvest practices, as four studies reported cost as a barrier to implementation of RMP *(7, 51, 61, 65)*.

PA scores for RMP implementation

PA scores were highest (90%) for animal control and lowest (55%) for food safety signage. Published studies reported high implementation levels (70 to 75%) of RMP related to wildlife and animal intrusion, including one study conducted with strawberry producers (n = 90) in the SE United States *(5, 78)*. Growers were reported to use animal preventive measures because of knowledge of outbreaks attributed to animals *(21, 26, 40, 44)*. Importantly, in 2011, 15 foodborne illness cases due to Shiga toxin-producing *E. coli* were reported due to eating fresh strawberries contaminated with deer feces, resulting in two deaths *(44)*. Apart from animal control, the next highest score was received for worker hygiene (88.1%). Worker hygiene is a key risk factor for strawberry contamination, as strawberries are often hand harvested and packed *(42)*. Therefore, growers may understand the importance of RMP leading to better implementation *(18, 51)*.

The lowest (55%) score for food safety signage may be due to the PSR not requiring the posting of food safety signage *(75)*. Visual and text signage are a better way to learn new information *(55, 64)*, so these types of signage could be incorporated into training as a means to increase RMP implementation. PA scores for strawberry storage and transportation were also low (55.6%), followed by harvesting and packing (66.7%) and agricultural water practices (70.2%). Although it is recommended to use separate vehicles for transporting produce, including strawberries, only five (56%) of nine farms in our sample had separate vehicles to transport produce, probably because our sample consisted of small farms. Besides the availability of separate vehicles, it is important to properly clean and sanitize transport vehicles and containers prior to hauling strawberries. Low PA scores for agricultural water practices were due to the unavailability of tested and treated agricultural water. Very small farms (i.e., as defined in the PSR) are required to comply with the PSR water requirements by 2024 *(74)*; therefore, training should emphasize these water requirements, as produce growers generally lack knowledge in RMP related to agricultural water *(51, 55, 64, 78)*. A study conducted in the north central region of the United States reported the least common behavior changes were implementing RMP for transportation of produce (15%) and testing of agricultural water for generic *E. coli* (20%) *(54)*.

Data collection was to be completed between March 2020 and April 2020, but due to the COVID-19 pandemic, it was postponed until June 2020. As a result, we could not assess all PA because strawberries were not in season in many states in the SE United States. Also, we could not conduct assessments in all 13 SE states because of COVID-19 restrictions regarding in-person human subject assessments. Finally, in-person assessments are resource and time intensive, so site visits were limited to two farms per state and were not generalizable to all small strawberry farms in the SE United States.

CONCLUSIONS

Implementation of RMP can be challenging and can be influenced by the availability of PA. Hence, we assessed the presence of PA on small strawberry farms. Although most PA were present on farms in our sample, the absence of some, such as safe agricultural water sources, body fluid spill kits, and food safety signage, suggests these topics need to be better addressed in training curricula. In addition, strawberry U-pick operations, which face unique challenges compared to conventional strawberry growers, were common among our sample so training specific to their needs should be created and offered. Future research studies should focus on establishing the relationship between PA and implementation of RMP. The findings from this study could be used to inform the development of a larger-scale survey.

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