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Survey of Implemented Mitigation Strategies and Further Needs of the U.S. Food Industry to Control COVID-19 in the Work Environment in Early 2021

ABSTRACT

Our objective was to determine the needs of the U.S. food industry to control COVID-19 in the work environment and what mitigation strategies are being implemented. A Web-based needs assessment survey was distributed in early 2021, targeting professionals in management positions at food industry facilities and operations. Statistical analyses were conducted on the self-reported adoption of mitigation strategies against COVID-19 in the participants' facilities and operations and the perceived needs of the industry regarding COVID-19. A total of 79 usable responses were received (those with data on the participant's industry sector), including 38 (48%) from the dairy, 17 (22%) from the fresh produce, and 24 (30%) from a mixture of other food industry sectors. Two usable responses were from the beef and pork sector, but none were from the poultry sector. Analyses revealed widespread implementation of mitigation strategies in the participants' facilities and operations. Participants perceived that collaboration between the food industry and government agencies, contingency plans and appropriate training, and new technologies are needed to control COVID-19 in the food industry. Subject to limitations associated with low participation, these findings will aid efforts in the represented U.S. food industry sectors to protect workers' health in the event of the emergence of a new SARS-CoV-2 variant or similar future disaster.

INTRODUCTION

The COVID-19 pandemic, caused by SARS-CoV-2, has presented substantial challenges to the food industry in the United States and worldwide. The food industry has dealt with disruptions in the supply chain *(7, 31, 35, 38, 63)*, difficulties meeting market demands and changes in food consumption patterns *(35, 57, 77)*, adverse effects on production capacity *(52)*, labor shortages *(25)*, an increase in food safety risks *(50, 68)*, and a decrease in productivity due to absenteeism *(33, 47, 51)* while adopting various public health measures to safeguard the health of the workforce *(53)*. The U.S. food industry, including transportation and logistics, is considered critical infrastructure for the nation because of its key role in feeding the U.S. population *(21)*.

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The COVID-19 outbreaks have occurred across major industry sectors in the U.S., including poultry, beef and pork *(76)*, dairy *(62)*, and fresh produce *(41)*. From April 2020 to July 2021, >90,000 cases and 450 deaths related to COVID-19 were reported across U.S. food industry sectors *(26)*. Some of these outbreaks have involved widespread transmission of COVID-19 among employees, as was the case for a central New York State greenhouse in which more than half of the workers (171 of 300) tested positive for the virus *(41)*. Food and agriculture are among the occupations most severely affected by excess deaths due to COVID-19, according to a study comparing the total number of deaths under two scenarios: one theoretical scenario in which COVID-19 never happened (established based on prepandemic data for 2018 and 2019) and one scenario in which deaths during the COVID-19 pandemic were projected *(18)*. To improve the ability of the U.S. food industry to more effectively and quickly respond to COVID-19-related disturbances and similar future disasters, it is essential to understand the needs and concerns of the food industry regarding the ongoing pandemic, and the impacts (e.g., COVID-19-related deaths), challenges, and responses to these challenges might differ across food industry sectors. For instance, industry sectors providing employees with housing and transportation might require additional preventive measures to avoid contact between COVID-19-infected and healthy employees *(13)*.

U.S. governmental institutions, such as the Centers for Disease Control and Prevention (CDC) and the Occupational Safety and Health Administration (OSHA), have published guidelines and checklists to inform and guide the U.S. food industry and other businesses about the correct implementation of physical distancing, biosafety, and surveillance strategies to prevent COVID-19 cases *(13, 16, 72, 73)*. The guidelines usually recommend the adoption of multiple methods to physically distance workers, sanitize and clean the workplace and workers' hands, enforce mask wearing, and use surveillance tests to identify COVID-19 cases and prevent further spread. These guidelines were established early in the COVID-19 pandemic (ca. June 2020) *(13, 73)* and before the widespread availability of vaccines to reduce transmission in the workplace (late 2020 to early 2021) *(16, 72)*. The proper implementation of these strategies is considered important for reducing the occurrence of COVID-19 cases in the workplace and/or limiting the size of outbreaks. For example, air ventilation and physical distancing were effective for reducing COVID-19 spread among employees in German meat industry facilities in 2020 *(56)*. However, it is unclear whether recommendations by government agencies and regulators can be readily implemented to control COVID-19 in food production facilities and operations. For example, facilities may be unable to implement certain strategies due to their cost and/or effects on production or the production environment (e.g., ventilation). Current information about the adoption of mitigation strategies in the U.S. food industry remains scarce and limited to certain sectors, such as the meat and poultry *(76)* and dairy *(78)* sectors. Although these studies have provided valuable information, they were performed in the comparatively early part of the COVID-19 pandemic (April to July 2020) when the adoption of mitigation strategies by the U.S. food industry would have been different (e.g., vaccine not yet available) and information, such as guidelines to implement ventilation in buildings *(16)* and OSHA's instructions to prevent COVID-19 transmission in the workplace *(72)*, had not yet been published. The study by Yung et al. *(78)* was restricted to dairy farmers in the states of Minnesota and Wisconsin, which represents a small part of the U.S. dairy industry and might not reflect the adoption of mitigation strategies in other dairy facilities and operations in the country.

This historical information is important because an understanding of how commonly physical distancing, biosafety, and surveillance mitigation strategies were adopted to prevent COVID-19 cases across the U.S. food industry and the reasons behind such adoption or lack of adoption are crucial for identifying areas where prevention could be improved. The objective of this study was to survey management professionals in the U.S. food industry to (i) identify the needs of the U.S. food industry (targeting produce farm operations and produce, dairy, poultry, beef, and pork processing facilities) for mitigating COVID-19 in food industry facilities and operations and (ii) determine what COVID-19 mitigation strategies have been implemented in the work environment. These objectives were addressed by administering a needs assessment survey between January and April 2021as detailed in the "Materials and Methods" section.

MATERIALS AND METHODS

Needs assessment survey design and data collection

A two-part Web-based needs assessment survey was developed. Part 1 included general questions about each survey participant's overall industry sector (produce, dairy, poultry, beef or pork, or other), and part 2 included questions about conditions and COVID-19 mitigation strategies in a food production facility or operation of the participant's choice (participants who oversaw multiple facilities and/or operations were asked to choose one). The wording of the questions is provided in Supplemental Material A *(Supplemental Table S1)*. Supplemental Material B contains a complete copy of the survey instrument, including the introduction letter and the consent statement. The part 1 questions were about a participant's industry sector, the main role in their organization, how COVID-19 has impacted their industry sector, concerns about COVID-19 control, challenges associated with maintaining production capacity, needs for successfully mitigating COVID-19, desired features

of a computational modeling tool that would aid decision making for control of COVID-19, and indicators of a successful response to COVID-19 cases. Part 2 included questions about the industry sector of the participant's selected facility or operation, maximum tolerable reduction in the production labor force that would be compatible with maintaining full production capacity, number and age of employees, availability of employer-provided housing and transportation for employees, the importance of various specialized job functions for maintaining production in the event of a COVID-19 outbreak, sources of COVID-19 in the facility or operation, and adoption of COVID-19 mitigation strategies (definitions of mitigation strategies provided to survey participants are shown in *Table 1*). In the survey instrument, "physical distancing" was referred to as "social distancing" because the latter term was more commonly used by the general public and government agencies at the time the survey was administrated. However, physical distancing is a more accurate term and was used in this article except when directly referring to questions from the survey instrument. In the survey instrument, in questions Q5 and Q9, "regulation" represented a broader concept of "regulations, guidance, and other requirements," which was used hereinafter for technical accuracy except when directly referring to the corresponding questions in the survey. Part 2 of the survey included several questions applicable to only participants from the produce industry sector. Survey questions were initially designed by E. Bulut, R. Ivanek, and S. Llanos-Soto. The design process included discussion of preliminary versions of the survey with A. Adalja, C. Zoellner, D. Wetherington, S. D. Alcaine, S. I. Murphy, and M. Wiedmann until a consensus was reached regarding the phrasing and content of the questions, included those in the piloted version of the survey. The survey was piloted between 8 December 2020 and 6 January 2021 by obtaining anonymous responses from seven of nine members of an advisory council for the authors' COVID-19 research grant; the council comprised executive-level managers representing the produce, dairy, beef and pork, and poultry industry sectors. Feedback from the piloting process was incorporated into the final version of the survey.

The survey was implemented in the Qualtrics (Provo, UT) survey platform and was made available online to survey participants through a link. After clicking on the link, participants were shown an introductory letter that provided information about the purpose of the survey and were asked to consent to take part in the study. Individuals >18 years of age and affiliated with a produce farm operation or with produce, dairy, beef or pork, poultry, or other food processing facilities in the U.S. were considered eligible to participate in the survey; recruitment targeted management professionals at those facilities and operations. No identifying information was collected from participants, and their responses remained confidential. No compensation for participation was provided *(Supplemental Material B)*. The survey took approximately 30 min to complete.

We contacted 21 food industry professional and trade organizations (5 produce; 5 dairy; 2 beef and pork; 2 poultry; 1 beef, pork, and poultry; and 6 general food processing) to request their assistance in disseminating the survey to their management professional members. This outreach resulted in successful collection of responses via 13 organizations: 3 associated with the fresh produce industry, 5 with dairy, 1 with beef, pork, and poultry, and 4 with general processing. The survey also was distributed via two social networks accessed by the study authors *(Table 2)*. The survey distribution period started on 19 January 2021 and concluded on 6 April 2021. The study was approved by the Cornell University Institutional Review Board for Human Participants (IRB protocol 2006009660). No power-based sample calculation was conducted because of the preliminary nature of the investigation. No response rate calculations were performed because the number of people invited to participate could not be known, given that the survey was distributed via social media and professional and trade organizations.

Data management and statistical analysis

Responses from only those participants who completed at least part 1 of the survey were considered usable *(Table 2)* because part 1 provided important context for part 2. Usable responses were organized in an Excel data sheet (Microsoft, Redmond, WA) for subsequent analysis. Some multiple choice and open-ended questions required specific numerical responses, which were subjected to statistical analyses. When a participant responded to a question asking for a specific number but instead gave an interval, the mean of the interval was used for the analysis. Incomplete responses or those unrelated to the corresponding questions were coded as missing values. Statistical analyses were carried out in R, v. 4.0.3 *(60)*. Responses to the survey questions were summarized and organized in tables and visually presented as heat maps. Numeric responses to open-ended questions were summarized with the median, mean, interquartile range (IQR), and range. Responses to Likert scale questions were treated as intervals (with assigned values of 1 through 5) or numbers (with assigned values of 0, 0.5, or 1) for statistical analysis so that the median score of responses to a Likert item could be calculated. Responses to Q20 "What was the average number of employees in this facility/operation in 2019?" were transformed from interval to nominal data by grouping responses into the levels "small" (1 to 49 employees), "medium" (50 to 249 employees), and "large" (>250 employees) based on criteria established by the Organisation for Economic Co-operation and Development *(54)*; this variable served as a proxy for facility or operation size.

A complete plan of analysis of survey questions can be found in *Table S1*, including questions identified as the outcomes of interest and independent variables (predictors) in the analysis of associations. As applicable, Kruskal-

TABLE 1. Definitions of physical distancing ("social distancing" in the survey instrument), biosafety, and surveillance mitigation strategies provided to study participants in the needs assessment survey

Intervention type, mitigation strategy	Definition of mitigation strategy
Physical distancing	
Installed physical barriers	Clear plastic partitions preventing employees from getting too close and preventing particles or droplets exhaled by one person from entering the breathing zone of another
Staggered break times	Groups of employees have different break times
Staggered arrival and departure times (staggered shifts)	Groups of employees have a set no. of hours to work during the day, but they have different start and finish times
Downsizing operation	Reduction of a facility's production capacity accompanied by a reduction in the no. of employees
Adjusted sick day policy	Employee benefits include a paid sick leave granted when an employee is unable to work because the employee is quarantined or isolated due to COVID-19, because of a bona fide need to care for an individual subject to quarantine or isolation, or to care for a child (<18 years of age) whose school or childcare provider is closed or unavailable for reasons related to COVID-19 (definition adapted from U.S. Dept. of Labor "Families First Coronavirus Response Act: Employee Paid Leave Rights")
Spacing workers >6 ft (1.8 m) during production	Keeping a space at least 6 ft between employees
Cohorting employees	Establishing groups of employees based on their risk of infection in the company, where each cohort remains as separated from the other cohorts as possible
Biosafety	
Enhanced hand washing	Implementation of a set of instructions for employees about when and how to wash hands that goes above and beyond instructions that were in place pre-COVID-19
Alcohol-based hand rubs	Implementation of a set of instructions for employees about when and how to use hand rubs
Face mask, face shields, and/or goggles	Implementation of a set of instructions about how and when to use face masks, face shields, and goggles. Face masks: often referred to as surgical masks or procedure masks, cover the nose and mouth, secured under the chin, fit snugly against the side of the face, do not have gaps. Face shields: secondary protectors intended to protect the entire face against exposure. Goggles: shield the eyes against hazards.
Increased air ventilation rates	Increase in the rate at which external air (fresh air) flows into the building
Air cleaning and/or filtering	Destroying or removing hazards such as virus particles from the air
Surveillance	
Temperature screening and quarantine	Screen for employees with a body temp >99.5°F (37.5°C) (or other cutoff value), and keep identified employees away from the workplace to determine whether they develop COVID-19 symptoms or test positive for the disease
Test for infection and isolation	Test employees for COVID-19 (virus test); isolation: keep an employee who is sick with COVID-19 or tested positive for COVID-19 without symptoms away from the workplace
Contact tracing and quarantine	Contact tracing: identify individuals who may have been exposed to a person with COVID-19; quarantine: separate individuals who have had close contact with someone with COVID-19 to determine whether they develop symptoms or test positive for the disease
Return to work postrecovery policy	Strategy implemented for employees returning to work following a COVID-19 case based on symptoms or doctor's recommendation

TABLE 2. Number of needs assessment survey responses (total received and usable) by industry sector and social media recruitment targets

Recruitment target	Recruitment venue	No. of responses	
		Total	Usable[a]
Fresh produce	United Fresh Produce Association; Produce Marketing Association; IAFP Professional Development Group (PDG) Fruit and Vegetable Safety and Quality	31	17
Dairy	Northeast Dairy Foods Association; International Dairy Foods Association; New York State Cheese Manufacturers' Association; IAFP PDG Dairy Quality and Safety Dairy Management Inc.	61	35
Beef, pork, poultry	IAFP PDG Meat and Poultry Safety and Quality	3	0
General processing	Minnesota AgriGrowth Council; American Frozen Food Institute (AFFI); Midwest Food Products Association; Food Northwest	29	17
Social media	LinkedIn; Twitter	21	10
Total		145	79

[a]A response was considered usable when participant completed at least part 1 of the survey.

Wallis, Fisher's exact, Mann-Whitney U, or Spearman's rank correlation tests were used to identify predictors associated with the outcomes of interest at the bivariate level. Associations were considered significant at $P \leq 0.05$. Post hoc assessment of significant associations was carried out using Dunn's test to determine specific differences between levels of each variable. Obtained *P*-values were adjusted for multiple testing by controlling the false discovery rate *(9)*. The data analyzed in this study are openly available at Zenodo (https://doi.org/10.5281/zenodo.6347758).

Thematic analysis

The thematic analysis involved determining common themes or ideas that were repeated across participants' open-ended responses to particular questions *(19)*. As a follow-up to certain Likert questions or multiple-choice questions, we asked an open-ended question to gain a deeper understanding of the participant's opinions or perceptions. These open-ended questions were preliminarily assessed to select questions with diverse and informative responses for thematic analysis. Questions with responses that provided new information (i.e., not being accounted for in responses to other questions in the survey) that was diverse enough to generate at least two codes were selected. During the initial assessment, a preliminary code book was generated to classify participants' responses into codes and subsequently identify themes emerging from those codes. This code book was further refined through discussions among some of the authors (S. Llanos-Soto, S. I. Murphy, E. Bulut, and R. Ivanek). Theme identification across questions was first carried out individually by the same four authors, and a final consensus was reached after discussion. Details for codes and themes can be found in *Table S2*.

RESULTS

Characteristics of survey participants and their facilities and operations

Responses were collected from a total of 145 survey participants. However, based on the decision to include responses from only those participants who completed at least part 1 of the survey (usable responses), responses from only 79 participants were retained for statistical *(Tables 3 through 5)* and thematic *(Table 6)* analysis. Among the 79 participants, 38 (48%) were from the dairy industry sector, 17 (22%) were from the fresh produce sector, and 24 (30%) were from other food industry sectors (e.g., beef and pork, chocolate, frozen food, prepared food, wine production, and cereals) (Q1) *(Table 3)*. Only two responses were obtained from the beef and pork industry; thus, these responses were grouped into the "other" category described above. Three participants self-reported association with all four food industry sectors (i.e., fresh produce, dairy, poultry, and beef and pork) and thus also were grouped into the "other" category. No responses were received from the poultry sector.

Some questions were very similar. Q1 in part 1 asked for the industry sector of a participant, which is different from Q15 in part 2 that asked about the industry sector of a facility or operation the participant (who oversees multiple facilities) chose to describe. This is why responses to Q1 and Q15 are slightly different, although they both ask about the industry sector.

TABLE 3. Number and proportion of responses among survey participants (N = 79) for questions, analyzed as categorical variables, from each of the two parts of the needs assessment survey

Question no.	Variable	Response		
		Text	No.	%
Part 1: General questions about a participant's industry sector				
1[a]	What industry sector are you in? (select all that apply)	Fresh produce	17	22
		Dairy	38	48
		Poultry	0	0
		Beef/pork[b]	2	3
		Other[c]	22	28
2[a]	Select your main role within your organization	C-suite	13	16
		Regional manager	0	0
		Facility manager	21	26
		Research and development	3	4
		Corporate food safety and quality	29	37
		Other[d]	11	14
		Prefer not to answer	2	3
3	Did COVID-19 have a significant impact on your industry sector?	Yes	67	85
		No	12	15
4	In which way(s) has COVID-19 significantly impacted your industry sector? (select all that apply)	Operations or production has been reduced or cut back	38	57
		Operations or production has expanded	23	34
		Implemented robotics, sensors, automation, and/or computer modeling	5	7
		Management or corporate employees working remotely	52	78
		Major changes in operational staffing control and protection protocols	54	81
		Other	1	1
Part 2: Conditions and COVID-19 controls in a facility or operation of participant's choice				
15[a]	In what industry sector is this facility/operation?	Fresh produce	17	22
		Dairy	40	51
		Poultry	0	0
		Beef/pork	1	1
		Other[e]	20	25
		No response	1	1

Continued on the next page.

TABLE 3. Number and proportion of responses among survey participants (N = 79) for questions, analyzed as categorical variables, from each of the two parts of the needs assessment survey (cont.)

Question no.	Variable	Response		
		Text	No.	%
20[f]	What was the average number of employees in this facility/operation in 2019?	Small (1–49 workers)	25	32
		Medium (50–249 workers)	33	42
		Large (>250 workers)	16	20
		Prefer not to answer	1	1
		Missing	4	5
22	Does this facility/operation provide group temporary (seasonal) housing to any of your employees?	Yes	9	11
		No	67	85
		No response	3	4
24	Does this facility/operation provide group transportation services (bus, truck, etc.) to employees to/from work?	Yes	8	10
		No	68	86
		No response	3	4
31	If in the future the available labor force in this facility/operation is affected by a COVID-19 outbreak, what short/mid-term solutions should be considered to maintain production? (check all that apply)	Extend the no. of work hours for remaining workers	59	75
		Backfill with emergency personnel from third-party companies	28	35
		Backfill by reorganizing personnel in the same facility	48	61
		No response	7	9
32	To prevent labor shortage in this facility/operation due to a potential future COVID-19 outbreak, should capital investment into mechanization be considered as a long-term solution to maintain production?	Yes	57	72
		No	13	16
		No response	9	11
43[a]	What was the main reason for your choice to describe conditions and COVID-19 mitigation in this particular food production facility/operation?	I am mostly familiar with this facility/operation	24	30
		This is our unique facility/operation	5	6
		This is our typical facility/operation	16	20
		This facility/operation has been impacted greatly by COVID-19	11	14
		This is our strategically important facility/operation	13	16
		Other	4	5
		No response	0	0
Questions applicable to only the fresh produce industry sector				
16[g]	How does this facility/operation operate?	All year	15	88
		Seasonally	2	12
		No response	0	0

Continued on the next page.

TABLE 3. Number and proportion of responses among survey participants (N = 79) for questions, analyzed as categorical variables, from each of the two parts of the needs assessment survey (cont.)

Question no.	Variable	Response		
		Text	No.	%
18[g]	What role best describes this facility/operation?	Grower	2	12
		Packing house	2	12
		Processor	4	24
		Grower and field packer	5	29
		Grower and processor	3	18
		Other	1	6
		No response	0	0
19[h]	Please select which part of your grower and processor operation will you describe in the remaining questions	Grower operation	0	0
		Processor facility	3	100
		No response	0	0

[a]Participants were required to answer the question to continue the needs assessment survey.

[b]Two participants from the beef and pork industry were grouped in the "other" category for statistical analysis.

[c]Participants who provided responses for the "other" industry sector (number of responses): food processing (2); frozen fruits (2); chocolate (1); cereal (1); copackaging of shelf-stable products (1); consumer packaged goods with fresh produce (1); food manufacturing (1); food service (1); frozen produce (1); manufacturing shelf-stable foods (1); prepared food (1); restaurants (1); seafood (1); spirits (1); sugar (1); vegetable processing (1). Another four participants were grouped into the "other" category for statistical analysis: one who is an academic researcher affiliated with the food industry and three who reported affiliation with all four sectors (i.e., fresh produce, dairy, poultry, and beef and pork).

[d]Participants who provided responses for the "other" main role within their organization (number of responses): quality assurance manager (3); sales service (1); affineur (1); human resources director (1); owner (1); office manager (1); CEO (1); emeritus professor (1); grower (1).

[e]Participants who provided responses grouped under the "other" industry sector for the described facility or operation of the participant's choice (number of responses): cleaning and sanitation (1); restaurants (1); chocolate (1); prepared food (1); food manufacturing (1); shelf-stable products (2); frozen produce (1); consumer packaged goods, sauces (2); cereal (1); food processing (2); beverage, spirits (1); vegetable processing (1); frozen fruits (2); seafood (1); sugar (1). One participant who answered "other" specified working in all industry sectors.

[f]Original levels of <10, 10 to 49, 50 to 99, 100 to 249, 250 to 499, 500 to 999, 1,000 to 2,000, and >2,000 were grouped in the levels small (1 to 49 employees), medium (50 to 249 employees), and large (>250 employees) based on criteria established by the Organisation for Economic Co-operation and Development.

[g]This question was shown to only 17 participants who selected the option "fresh produce" for Q15.

[h]This question was shown to only three participants who selected the option "grower and processor" for Q18.

The most common roles of the 79 participants in their organizations were corporate food safety and quality manager (29 participants, 37%) followed by facility managers (21 participants, 27%) and c-suite executive (13 participants, 16%) (Q2) *(Table 3)*. Most participants (67 of 79, 85%) indicated that COVID-19 has significantly impacted their industry sector, most commonly through major changes in operational staffing control and protection protocols (54 participants, 68%), remote work of management or corporate employees (52 participants, 66%), and reduced operations or production (38 participants, 48%) (Q4) *(Table 3)*.

In terms of the average number of employees in 2019, most participants (33 of 79, 42%) described a medium-size facility or operation (50 to 249 employees) (Q20) *(Table 3)*. The largest reduction in the general production labor force in a single week that the participants' facility or operations could

TABLE 4. Summary statistics for questions included in part 2 of the needs assessment survey (conditions and COVID-19 controls in a food production facility or operation of participant's choice), which were analyzed as interval variables for 79 survey participants

Question no.	Variable	Mean	Median	IQR	Range	No response
26	What is the largest percent reduction in the general production labor force that this facility/operation could withstand over a period of 1 week without reduction in the production capacity?	15	15	10–15	5–50[a]	13[b]
21	What is the approximate proportion (%) of employees in this facility/operation that are 50–69 years of age?[c]	32	28	20–40	0–100	13
21	What is the approximate proportion (%) of employees in this facility/operation that are ≥70 years of age?[c]	3	1	0–5	0–17	17
23	Approximately what proportion (%) of employees in this facility/operation are provided with group temporary housing?[d]	49	35	35–70	10–100	2
25	Approximately what proportion (%) of employees in this facility/operation are provided with group transportation to/from work?[e]	40	28	15–63	10–90	1

[a]This was a single-choice question with available responses: 5, 10, 15, 20, 30, 40, and 50% and do not know; thus, the observed range spanned the full range of possible responses.

[b]Nine participants responded "do not know" and were grouped with "no response" for analysis.

[c]The original question asked about employees 50 to 69 years of age and ≥70 years but were separated here to more clearly indicate their values.

[d]This question was shown to only nine participants who selected "yes" for Q22: "Does this facility/operation provide group temporary (seasonal) housing to any of your employees?"

[e]This question was shown to only eight participants who selected "yes" for Q24: "Does this facility/operation provide group transportation services (bus, truck, etc.) to employees to/from work?"

withstand without reducing their production capacity had a median of 15% (IQR: 10 to 15%) (Q26) *(Table 4)*. Only 11 and 10% of the participants' facilities or operations provided employees with group temporary (seasonal) housing and transportation, respectively (Q22 and Q24) *(Table 4)*. Most participants (57 of 79, 72%) agreed that capital investment into mechanization should be considered a long-term solution to maintain production in the face of a future COVID-19-associated labor shortage (Q32) *(Table 3)*.

Needs, concerns, and challenges related to COVID-19

Regarding the control of COVID-19 in their industry sector (Q5) *(Supplemental Fig. S1A)*, the majority of participants considered labor availability and complex ever-changing government regulations very concerning (median = 4). Conversely, workers' abuse of control measures, limited financial resources, and product quality were only slightly concerning (median ≤ 2) to most survey participants *(Fig. S1A)*. Concern about limited financial resources was significantly higher in small than in medium ($P = 0.04$) and large ($P = 0.04$) facilities or operations and was also significantly higher in the fresh produce industry sector than in the dairy sector (Q5, $P = 0.05$) *(Table 5)*. Similarly, concern about supplier management was also significantly higher in small than in large facilities or operations (Q5, $P = 0.03$) *(Table 5)*. Participants also stated concerns about factors related to employees, COVID-19 mitigation, and supply chain (thematic analysis of Q6) *(Table 6)*. Regarding employee's mental health, a participant stated the following: "Mental health impact on managerial and office staff. In talking with industry colleagues, my experience is that many facilities have cut back on the staff responsible for ensuring that the facility is operating in an efficient and structured manner, while expanding the production capacity of the

TABLE 5. Significant associations found in the bivariate analyses ($P \leq 0.05$) between a specific Likert item (outcome) in a survey question and independent variables (predictors) describing industry sector (Q1) and facility or operation size (Q20) after post hoc analysis and false discovery rate adjustment[a]

Likert question[b]	Item	Predictor	Level[c]	Median[d]	IQR[d]
5. Regarding control of COVID-19 in your industry sector, how concerning are these items?	Limited financial resources	Facility, operation size	Small A	3.5	2–5
			Medium B	2	2–3
			Large B	2	1–3.3
	Limited financial resources	Industry sector	Dairy A	2	1–3
			Fresh produce B	3	2–4
			Other AC	3	2–4
	Supplier management	Facility, operation size	Small A	3	3–5
			Medium AB	3	2–4
			Large BC	2	2–3.3
9. Regarding needs to successfully mitigate COVID-19 in your industry sector, how important are these items?	Easier way to understand regulations	Industry sector	Dairy A	4	3–4
			Fresh produce B	5	3–5
			Other AC	3	2–4
13. Regarding indicators of successful responses to COVID-19 in your industry sector, how important are these items?	Established effective risk communication plan	Facility, operation size	Small A	3.5	3–4
			Medium AB	4.0	4–5
			Large BC	5.0	4–5
29. Regarding potential sources of COVID-19 infection in this facility/ operation, how concerning are these items?	Indoor common areas	Facility, operation size	Small A	2.5	1–4
			Medium B	4	3–4
			Large AC	3	2–4
34. Have any of these social distancing strategies been applied in this facility/ operation at any point since the start of the COVID-19 pandemic?	Installed physical barriers	Facility, operation size	Small A	0	0–0.6
			Medium B	1	0.5–1
			Large B	1	0.5–1
	Staggered break times	Facility, operation size	Small A	0	0–1
			Medium B	1	1–1
			Large B	1	0.5–1
	Staggered arrival, departure times (staggered shifts)	Facility, operation size	Small A	0	0–0.5
			Medium B	1	0–1
			Large B	0.5	0–1
	Adjusted sick day policy	Facility, operation size	Small A	0	0–1
			Medium B	1	0.5–1
			Large AB	0.8	0.5–1
	Spacing workers >6 ft (1.8 m) during production	Facility, operation size	Small A	0.5	0–0.5
			Medium B	1	0.8–1
			Large B	1	0.5–1

Continued on the next page.

TABLE 5. Significant associations found in the bivariate analyses ($P \leq 0.05$) between a specific Likert item (outcome) in a survey question and independent variables (predictors) describing industry sector (Q1) and facility or operation size (Q20) after post hoc analysis and false discovery rate adjustment[a] (cont.)

Likert question[b]	Item	Predictor	Level[c]	Median[d]	IQR[d]
	Spacing workers >6 ft (1.8 m) during production	Industry sector	Dairy A	1	1–1
			Fresh produce AB	0.5	0.5–1
			Other BC	1	0.5–1
	Cohorting employees	Facility, operation size	Small A	0	0–0
			Medium B	0.5	0–1
			Large AB	0.5	0–0.6
36. Have any of these employee biosafety strategies been applied in this facility/ operation at any point since the start of the COVID-19 pandemic?	Face mask, face shields, goggles	Industry sector	Dairy A	1	1–1
			Fresh produce B	1	0.5–1
			Other AC	1	1–1
	Air cleaning, filtering	Facility, operation size	Small A	0	0–0.1
			Medium B	1	0–1
			Large AB	0.5	0–1
38. Have any of these surveillance strategies been applied in this facility/ operation at any point since the start of the COVID-19 pandemic?	Temperature screening and quarantine	Facility, operation size	Small A	0.3	0–1
			Medium B	1	1–1
			Large AB	1	0.5–1
	Contact tracing and quarantine	Facility, operation size	Small A	0	0–0.8
			Medium B	1	1–1
			Large B	1	0.9–1
	Contact tracing and quarantine	Industry sector	Dairy A	1	1–1
			Fresh produce B	0.5	0.5–1
			Other AB	1	0–1
	Return to work Postrecovery policy	Facility, operation size	Small A	1	0.4–1
			Medium B	1	1–1
			Large AB	1	0.9–1

[a]Other statistically significant associations found in this study are presented in Table S3.

[b]Likert question number in the needs assessment survey.

[c]Level designations followed by different capital letters are significantly different, that is, the Likert responses for the outcome variable were significantly different between the two levels of a predictor. Responses for levels with the same letter were not significantly different.

[d]Median and interquartile range (IQR) calculated for the interval (1 through 5 for Q5, Q9, Q13, and Q29) and numeric values (0, 0.5, or 1 for Q34, Q36, and Q38) that were assigned to the Likert scale responses in each Likert item are included for comparison across facility and operation size and industry sector levels. For Q5 and Q29, values 1 through 5 represented "not at all concerning" to "extremely concerning"; for Q9 and Q13, values 1 through 5 represented "not at all important" to "extremely important". For Q34, Q36, and Q38, 0 represented "no" (not implemented), 0.5 represented "yes, but only partially/temporarily," and 1 represented "yes."

TABLE 6. Themes identified in participants' responses to selected open-ended questions in the needs assessment survey, the purpose of which was to provide depth to the corresponding Likert items questions

Question no.[a]	Open-ended question	No. of responses	Themes
5	6. Regarding control of COVID-19 in your industry sector, are there any other concerns we should consider?	19	Employee fatigue, vaccine hesitancy, health and health care access; access to COVID-19 preventive measures, guidance, and information; difficulties in implementation of mitigation strategies; supply chain disruption and management of contractor expectations
7	8. Regarding the labor force needed to maintain the production capacity in your industry sector during the COVID-19 pandemic, are there any other challenges we should consider?	20	Downside of COVID-19 mitigation strategies; government benefits and regulations, guidance documents, and other requirements; labor availability, needs, expectations, and behavior
9	10. Regarding needs to successfully mitigate COVID-19 in your industry sector, are there any other important needs we should consider?	8	Technology to improve infection prevention, time efficiency, and Internet access; cost-effective mitigation strategies, harmonized guidance, and prioritized vaccination of food industry workers; consumer education
32	33. To maintain production in the event of labor shortage in this facility/operation due to a potential future COVID-19 outbreak, are there any other solutions we should consider?	9	Employee benefits and training; industry collaboration, production adjustment, and infrastructure changes
34	35. For one or more of these social distancing strategies, could you share any reasons for adopting or not adopting it, such as cost, compliance by workers, training requirement, effectiveness in reducing health risks, impact on production capacity, and/or lack of science-based information?	12	Infrastructure, productivity, or union-imposed constraints; lack of concern or need
36	37. For one or more of these employee biosafety strategies, could you share any reasons for adopting or not adopting it, such as cost, compliance by workers, training requirement, effectiveness in reducing health risks, impact on production capacity, and/or lack of science-based information?	10	Infrastructure constraints; lack of funds, supplies, or information; lack of need
38	39. For one or more of these surveillance strategies, could you share any reasons for adopting or not adopting it, such as cost, compliance by workers, training requirement, effectiveness in reducing health risks, impact on production capacity, and/or lack of science-based information?	10	Cost of implementation; increases worker absences; lack of concern or need

[a]The complete wording of the Likert questions can be found in *Table S1*.

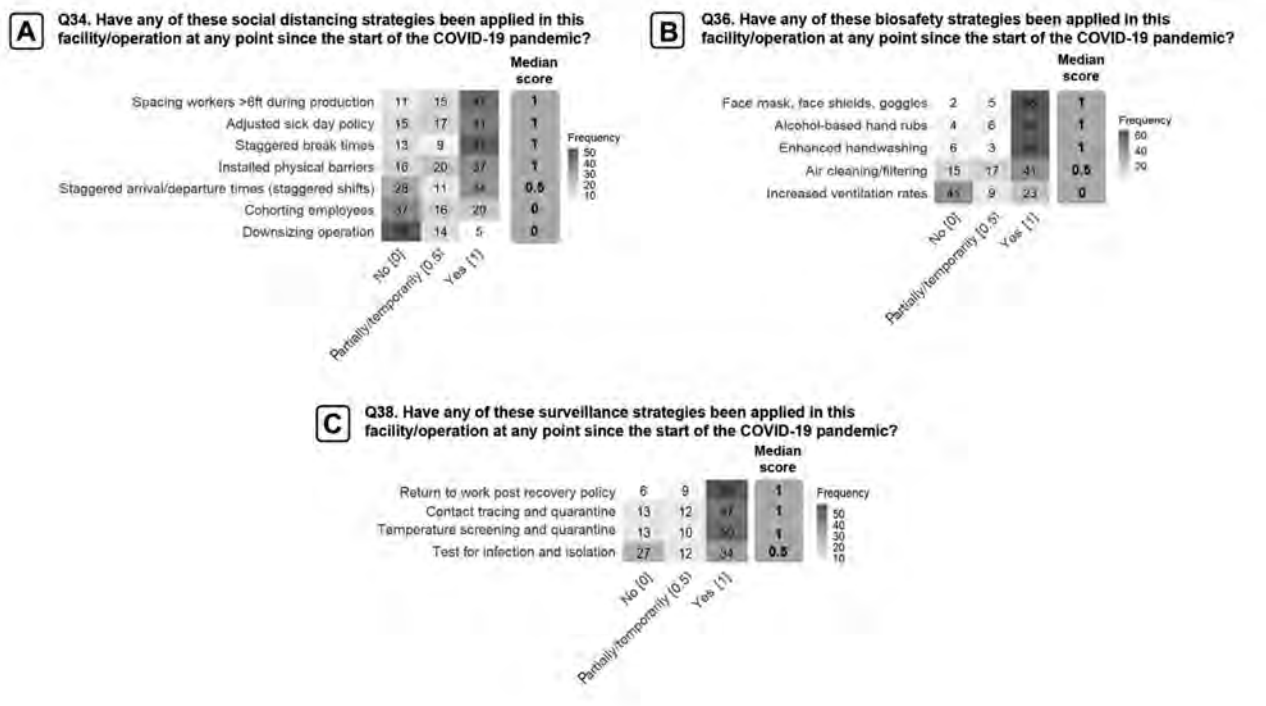

Figure 1. Responses to questions about the implementation of physical distancing (worded as "social distancing" in the survey instrument) (A), biosafety (B), and surveillance strategies (C) in a facility or operation of participant's choice. For each specific mitigation strategy, a median score (shown to the right of the heat map) was calculated from the numerical values 0, 0.5, and 1 assigned to answers "no," "yes, but only partially," and "yes," respectively.

facility. It leaves many of these employees in a position where they are stretched thin and feel overwhelmed."–Participant 75, other industry sector (copackaging of shelf-stable products).

Among challenges associated with the labor force needed to maintain the production capacity (Q7) *(Fig. S1B)*, most participants perceived that all of the items presented to them were at least moderately challenging (median ≥ 3); the need to train labor, access to workers with necessary skills, and access to number of workers needed were considered very challenging (median = 4). Additional challenges to maintaining the production capacity were related to COVID-19 mitigation, employee, and government factors (thematic analysis of Q8) *(Table 6)*.

In particular, one participant expressed frustration when dealing with continuously changing government regulations, guidance documents, and other requirements: "Government directives and laws regarding labor, time off, and pay rules and the changes in these made managing government special rules a full-time job, rather than managing the pandemic we were managing the labor law compliance tasks."–Participant 45, fresh produce industry sector.

Regarding needs to successfully mitigate COVID-19 in their industry sector (Q9) *(Fig. S2A)*, most participants indicated that an easier way to understand regulations was the most important (median = 3.5); this item was considered more important by the fresh produce industry than by the dairy industry ($P = 0.05$) and the group of "other" industry sectors ($P = 0.03$) *(Table 5)*. Participants further stated needs for improved technology solutions, mitigation strategies, and consumer education (thematic analysis of Q10) *(Table 6)*.

If a computational modeling tool were available to predict which COVID-19 mitigation strategies would be the most successful in a given facility (Q11) *(Fig. S2B)*, all model features proposed in the survey (e.g., ease of use, confidentiality, and customization) would be considered very important (median = 4). Regarding the question about indicators of successful responses to COVID-19 in their industry sector (Q13) *(Fig. S2C)*, participants perceived that almost all items listed in the question were very important (median = 4), but large facilities and operations were more likely to have established effective risk communication plans than were smaller facilities and operations (Q13, $P = 0.03$) *(Table 5)*.

Regarding the risk of shutdown associated with the facility or operation due to work absences for certain specialized job functions (Q27) *(Fig. S3A)*, participants indicated that specialized production line functions, engineering and/or maintenance crew, and sanitation and cleaning presented a high risk of shutdown (median = 4). Regarding potential

sources of COVID-19 spread in the facility or operation (Q29) *(Fig. S3B)*, participants were particularly concerned about activities in the local community (median = 4). Respondents from medium-size facilities or operations were more likely to be concerned about indoor common areas as a potential source of COVID-19 than were small ($P = 0.04$) and large ($P = 0.05$) facilities or operations (Q29) *(Table 5)*.

Implemented mitigation strategies

Among physical distancing measures (Q34) *(Fig. 1A)*, installed physical barriers, staggered break times, adjusted sick day policy, and spacing workers >6 ft (1.8 m) during production were all implemented or were partially or temporarily implemented by most facilities or operations. Downsizing operations and cohorting employees were the least often implemented physical distancing strategies *(Fig. 1A)*. Small facilities or operations implemented several physical distancing strategies significantly less frequently than did medium-size and large facilities and operations, including installing of physical barriers ($P = 0.005$ and $P = 0.005$, respectively), staggered break times ($P < 0.001$ and $P = 0.004$, respectively), and staggered shifts ($P = 0.02$ and $P = 0.04$, respectively) (Q34) *(Table 5)*. In addition, medium-size facilities and operations were more likely to adopt an adjusted sick day policy ($P = 0.003$) and cohorting employees ($P = 0.02$) than were small facilities and operations (Q34) *(Table 5)*. Stated reasons for the nonimplementation of physical distancing measures were constraints related to the infrastructure, productivity, and union-imposed restrictions and the perceived lack of need or concern (thematic analysis of Q35) *(Table 6)*. For example, one participant expressed concern about downsizing the operation as a strategy to contain the infection spread: "If the plant does not run near full production, we are out of business."–Participant 56, dairy industry sector.

Enhanced hand washing, use of alcohol-based hand rubs, and use of face mask, face shields, and goggles were the most commonly implemented biosafety strategies (Q36) *(Fig. 1B)*. The face covering strategy was implemented more often in facilities or operations in the dairy and "other" industry sector group than in the fresh produce sector (Q36, $P = 0.002$ and $P = 0.05$, respectively) *(Table 5)*. Air cleaning or filtering was implemented, partially, or temporarily in a little more than half of the facilities or operations; medium-size facilities and operations were more likely to adopt this measure than were small facilities and operations (Q36, $P = 0.01$) *(Table 5)*. Less than half of the facilities and operations adopted increased ventilation rates (Q36) *(Fig. 1B)*. The responses to the corresponding open-ended question indicated that the lack of implementation of biosafety interventions was due to infrastructure constraints, lack of funds, lack of supplies or information, or the perceived lack of need (thematic analysis of Q37) *(Table 6)*.

Among surveillance strategies (Q38) *(Fig. 1C)*, temperature screening and quarantine, return to work post-recovery policy, and contact tracing were commonly adopted among facilities and operations. Contact tracing and quarantine ($P < 0.001$), temperature screening and quarantine ($P = 0.006$), and return to work post-recovery policy ($P = 0.002$) were more commonly adopted in medium-size than in small facilities or operations (Q38) *(Table 5)*. Contact tracing and quarantine were also more commonly implemented in large than in small facilities or operations ($P < 0.001$). Dairy facilities more commonly adopted contact tracing and quarantine as a surveillance measure than did the fresh produce sector (Q38, $P = 0.02$) *(Table 5)*. Participants indicated that the reasons for not implementing surveillance strategies were the cost of implementation, the increase in worker absences, and the perceived lack of concern or need (thematic analysis of Q39) *(Table 6)*. For example, two participants described challenges due to increased absences when implementing temperature screening: "Temperature screenings aren't sufficient, as they aren't always going to detect a mild case. Temperature gun is 30 to 60 dollars. On site Covid tests are borderline unavailable to small and medium sized companies."–Participant 56, dairy industry sector. "We do daily employee temperature readings but have had to isolate many employees for symptoms other than low grade fevers such as backaches, coughing, fatigue, etc."–Participant 46, fresh produce industry sector.

DISCUSSION

The goal of this study was to identify the needs of the U.S. food industry for controlling COVID-19 in the work environment and to determine what mitigation strategies were implemented in early 2021. Information on this matter is crucial to determine both how the U.S. food industry has already responded to the pandemic and what is still required to enhance its resilience in the face of current and future similar events to ensure that an adequate, safe, and nutritious food supply is maintained. The main findings from this study suggest that for the represented sectors of the U.S. food industry, (i) mitigation strategies have been widely implemented in facilities and operations except strategies that reduce productivity, involve major costs, or/and had insufficient information on cost-effectiveness; (ii) facility or operation size and industry sector may impact decision making regarding implementation of COVID-19 mitigation strategies; and (iii) challenges and opportunities remain for control of COVID-19 and similar disasters. Survey responses were collected from January 2021 to April 2021, a period in which COVID-19 cases in the U.S. food industry were still occurring but declining *(26)*. During this time, vaccines were just becoming available in the U.S. and access was prioritized for essential non–health care workers *(14)*, including food industry employees, and the percentage of fully vaccinated people among those eligible was 0 to 21% during that period *(40)*. Thus, the results presented in this study reflect the state of the represented U.S. food industry sectors in early 2021

regarding the perceived needs and implemented mitigations for control of COVID-19 transmission in the workforce.

Implemented mitigation strategies

The study participants self-reported adoption of most physical distancing mitigation strategies included in the survey except those measures that negatively impacted production capacity, namely cohorting employees and downsizing operations. The widespread adoption of most physical distancing strategies across the assessed food industry sectors is not surprising because of the well-established key role such strategies play in reducing the occurrence of COVID-19 cases in various work settings *(44)* and countries *(67)*. The continuous promotion of such measures since the beginning of the COVID-19 pandemic and the availability of updated guidance on how to implement these measures likely facilitated their adoption by food facilities and operations *(16, 71)*. For example, a COVID-19 outbreak that occurred in a Colorado mushroom farm on 6 May 2020 was rapidly controlled, and further virus dissemination was prevented based on available public health guidance *(5)*. We hypothesize that the common adoption of physical distancing mitigation strategies is partly due to the availability of funding programs launched by the U.S. federal government to financially assist businesses during the pandemic. These programs include the Coronavirus Aid, Relief, and Economic Security Act, the COVID-19 Economic Injury Disaster Loan, and the Coronavirus Food Assistance Program, which provided food facilities and operations with financial resources to implement physical distancing *(69, 70, 74, 75)*. Despite these programs, survey participants expressed concerns about financial challenges that limited their ability to install physical barriers, suggesting that additional sources of funding are necessary to further incentivize the adoption of such measures and that companies need to budget in advance for emergency preparedness and responses. Overall, findings from this study suggest that the common adoption of physical distancing strategies and the current availability of detailed guidance for their implementation will contribute to the rapid implementation of physical distancing controls in response to new SARS-CoV-2 variants in the current pandemic, future COVID-19 pandemics, and similar disasters.

Our survey also revealed that physical distancing measures based on cohorting employees and in particular downsizing operations were rarely implemented, possibly because businesses avoid strategies that would reduce production capacity or present organizational disruption *(79)*. Downsizing was used by some businesses during the COVID-19 pandemic to contain the outbreak in a facility or operation even in late 2020 *(33)*, albeit at the cost of reduced production capacity. For instance, capacity reduction in the Canadian beef and pork industry led to financial setbacks for businesses and increased the cost to maintain animals for an extended period before slaughter *(33)*. Downsizing and the increase in sickness-related absences caused an increase in work-related physical demands and job insecurity, which had negative impacts on employees' mental health *(43)*. One survey participant in this study described food industry employees' struggles with mental health issues after downsizing. Thus, when facilities or operations plan on adopting or are forced to adopt downsizing as a strategy to reduce COVID-19 transmission, measures should be taken to prevent downstream food supply disturbances and production losses and to protect employees' mental well-being. Further studies are needed to determine the specific economic and other effects of downsizing on the U.S. food industry facilities and operations and their workers before and during the COVID-19 pandemic.

The survey participants indicated that cheap and easy biosafety mitigation strategies were widely adopted by produce farm operations and food processing facilities, but more information is needed about the cost-effectiveness of air cleaning and filtering and ventilation in general. The use of personal protective equipment (PPE) self-reported in our study agrees with an earlier report from Waltenburg et al. *(76)*, who reported that 86 (77%) of 111 meat and poultry processing facilities required workers to wear masks. However, survey participants in our study mentioned that the lack of access to preventive measures, including PPE, was an important concern in efforts to control COVID-19 in their industry sector. Previous reports indicated that the lack of supplies due to disruptions in the supply chain *(20, 23)* early in the COVID-19 pandemic was a severe challenge for businesses, even for front-line essential workers in health care institutions in the U.S. *(1)* and abroad *(1, 42)*. Thus, establishing a reliable and efficient system to ensure PPE availability and distribution to food facilities and operations is essential for the success of disaster preparedness plans for future pandemics. Our findings suggest that sectors of the food industry represented in this survey are prepared to implement biosafety strategies in the event of a new SARS-CoV-2 variant, future COVID-19 pandemics, or similar disasters caused by airborne pathogens, but successful adoption will critically depend on the establishment of measures to strengthen the local and global supply chain of PPE and other relevant resources.

In contrast to other biosafety strategies evaluated in our survey, air filtering and ventilation were rarely implemented among facilities and operations. For some participants' facilities, there was a concern that ventilation would disrupt the controlled environmental conditions required for production. Some participants mentioned that air filtering was considered an unnecessary investment when other mitigation strategies were already in place. However, a somewhat unexpected finding was that another reason ventilation and air filtering were not implemented was insufficient guidance and information about cost-effectiveness, although these strategies had been recommended in late 2020 by the CDC

as engineering controls (i.e., measures that do not interfere with employees' work but reduce the spread of COVID-19) *(16)*. Poor air quality and airflow inside meat and poultry processing plants have been associated with an increased risk of workers becoming infected with COVID-19 *(56)*. The CDC recognizes the challenges associated with the use of ventilation as a COVID-19 control strategy *(16)*. Installation of air filtering and ventilation systems is a more complex process compared with other recommended biosafety strategies to combat COVID-19 because it requires consideration of several additional factors, including the selection of systems adequate for the size, occupancy level, and specific features (e.g., production environment) of each facility *(11)*. Because of the complexity of installing air filtering and ventilation systems *(16)* and the ongoing discussion about the effectiveness of some of these methods for collecting and/or removing viral particles in the air *(34)*, we hypothesize that facility management will favor other more commonly recommended control strategies that are easier to implement to prevent COVID-19 transmission. The survey findings highlight the importance of further research and guidance about the implementation of air filtering and ventilation and their advantages in terms of cost-effectiveness over other mitigation measures.

Most surveillance strategies were widely implemented by the participants' produce grower operations and food processing facilities. This finding is not surprising considering that virus testing and isolation, contact tracing, and quarantine of contacts have been proposed as useful methods to prevent COVID-19 transmission in the community *(6, 59)*. These methods have also been promoted by the CDC and OSHA as ways to reduce COVID-19 dissemination in the workplace *(15, 70)*. An early report of mitigation strategies used in the food industry pointed out temperature screening as a widely applied method in the U.S. poultry and meat industry sectors *(76)*, and this strategy was recommended by the CDC and OSHA for implementation in food industry facilities and operations *(13, 73)*. Findings from the survey support that in facilities and operations where virus testing and isolation were not implemented, the likely reason was the associated financial burden, reflecting both the cost of testing and losses due to absences of isolating workers and the related production losses. Overall, our findings suggest that the U.S. food industry is willing to apply surveillance measures to prevent further transmission of COVID-19 cases in their facilities and operations, but access to these measures needs improvement and they must be strategically applied to avoid increasing the costs associated with absenteeism and productivity loss.

Regarding temperature screening, some survey participants expressed distrust of this measure for detection of mild cases of COVID-19, a topic that has been a matter of discussion throughout the pandemic *(10, 28, 48, 64)*. A survey study directed at food-related companies in 16 countries (mainly in Europe) revealed that temperature screening of workers was considered of limited importance for preventing the effects of the COVID-19 pandemic in food companies *(24)*. Reports have suggested poor sensitivity *(55)* and specificity *(17, 46)* of temperature screening (both infrared thermometers and thermal imaging cameras) when used to detect mild COVID-19 cases. Poor specificity resulting in many false-positive results, leading to an unnecessary increase in absenteeism and the associated rise in costs due to productivity loss. Chen et al. *(17)* found that the specificity for infrared thermometers was 61 and 67%, depending on the part of the body being measured (wrist and forehead, respectively). This drawback is extremely important for labor-intensive sectors of the food industry, which rely on the availability of qualified workers to continue food production. Temperature screening has been proposed as a valuable and easily implemented tool to reduce COVID-19 cases, particularly at the beginning of the pandemic when the knowledge about the virus and the effectiveness of preventive methods and available guidance was limited *(22, 39)*. However, given the issues associated with this strategy, the increased access to vaccination against COVID-19, and the widespread implementation of other controls in the food industry, temperature screening as a surveillance strategy and how it is implemented (if needed) should be reevaluated to avoid increasing absenteeism among workers.

Facility and operation size and industry sector

Large and medium-size facilities and operations represented by the survey participants more frequently implemented physical distancing, biosafety, and surveillance mitigation strategies than did small businesses. Due to scale economies, implementation of mitigation strategies might lead to a greater reduction in production capacity for smaller than for larger businesses, resulting in greater economic losses that cannot be sustained by those small businesses, as evidenced by studies pointing out their lack of financial resilience to sustain the impacts of COVID-19 *(8, 29)*. For example, the implementation of complex measures such as air cleaning and filtering, which entail high fixed costs, is likely to be economically infeasible or even unnecessary for operations that have only a few employees. Findings from the survey revealed that small facilities and operations are more commonly concerned about funding. Participants also mentioned that small facilities and operations struggled to manage COVID-19–related work absences and that better financial support is required to assist small to medium-size businesses. Because small businesses typically lack access to the types of financial resources readily available to larger firms (i.e., institutional funding), it is important to continue research *(3, 4)* directed at developing cutting-edge and low-cost technologies to assist small businesses in responding to the COVID-19 pandemic.

Participant responses indicated that facilities in the dairy industry sector more commonly adopted specific biosafety and surveillance mitigation strategies than did those in the fresh produce industry sector, whereas the latter were more likely to be concerned about funding and required easier approaches to understand continuously changing governmental regulations, guidance documents, and other requirements. We hypothesize that the comparatively lower adoption of PPE in the fresh produce industry is due to some operations (farms) conducting work outdoors in fields where the use of goggles and face shields might prevent employees from performing their tasks efficiently. In contrast to dairy processing plants, the decentralized nature of the fresh produce industry coupled with the significant heterogeneity in operating practices suggest that not all mitigation strategies may be appropriate for some operations. Differences may also exist in how consistently both the fresh produce and dairy industry sectors can access mitigation strategies; survey participants from the fresh produce sector expressed concerns about funding limitations. Our survey findings indicate that the fresh produce industry sector also needed easier approaches to understand the continuously evolving governmental regulations, guidance documents, and other requirements, potentially due to the continuous turnover of the seasonal workforce. These findings reveal important differences in terms of challenges and needs of the dairy and fresh produce industries and further suggest that innovative approaches are needed for fresh produce operations to overcome the limitations in PPE use and develop novel strategies to train the newly recruited workforce more efficiently.

Challenges and opportunities to control COVID-19

The survey participants considered the establishment of plans and guidelines as very relevant for controlling current and future COVID-19 outbreaks. These approaches would enhance the ability of U.S. food industries to effectively respond to disruptions in a timely manner considering the consequences of the COVID-19 pandemic, particularly at the beginning *(77)*. Our findings are consistent with those of a previous study calling for the food industry to proactively establish plans and mitigation strategies to assist in building resiliency and ensuring the correct continuation of the productive process *(12)*. Plans and guidelines for controlling the COVID-19 pandemic and similar disasters should be established by taking into consideration the complexity of the food supply chain. Government and businesses should develop contingency plans to be prepared to effectively address food safety risks, workforce reduction, economic losses, and facility shutdowns as consequences of the simultaneous effects of mitigation strategies or worker absences due to infection *(7, 51)*, dramatic changes in demand for products *(37, 45)*, modifications to product specifications (e.g., package size) *(37, 45)*, government-mandated suspension of operations *(37, 45)*, and facility shutdown-related increases in work absences *(77)*.

The survey participants also acknowledged the importance of training employees in risk mitigation strategies to prevent COVID-19 transmission in their food facilities and operations. This finding was expected given that training has been a fundamental tool to educate the workforce on how to behave during the pandemic, correctly implement mitigation strategies, and understand the current state and federal rules and regulations, guidance documents, and other requirements around the COVID-19 pandemic *(53)*. Guidelines and training resources made available by the CDC and OSHA have been useful for training employees in the use of PPE and physical distancing practices in the workplace and for identification of signs and symptoms associated with COVID-19 cases. Ensuring access to the Internet in facilities and operations located in remote areas is also crucial to allow these facilities to implement training strategies promptly, a need expressed by survey participants. Internet access also is essential if novel technologies, such as augmented and virtual reality, are to be implemented for training the workforce on disaster preparedness *(32)*. Previous reports have indicated the important advantages of these novel approaches compared with traditional training methods, including the opportunity to physically distance while allowing workers to immerse themselves in the activity at hand and learn effectively *(2)*.

The development of new technological approaches to respond to the COVID-19 and future pandemic events (e.g., due to new SARS-CoV-2 variants) was considered important by the survey participants. The COVID-19 pandemic has resulted in accelerated development of new technologies to promptly assist the food industry in dealing with the COVID-19 pandemic and beyond *(32)*. Future advances in digitization and big data analysis will help the food industry rapidly respond to COVID-19–related or other similar disruptions through improved access to knowledge for decision making *(38)*. For instance, the design of modeling tools to predict the impacts of COVID-19, including costs associated with absenteeism, effects on productivity, and implementation of available mitigation strategies, would allow the food industry to better manage an ongoing pandemic. Improvements in data collection and management, such as shared access to data and data traceability, can facilitate relevant improvements in the efficiency of the food supply chain, and the implementation of automation and robotic technologies could assist in improving food security and facilitate the adoption of physical distancing measures to prevent transmission of airborne pathogens *(37, 38)*. The development of new technologies will assist in building resilience to withstand COVID-19-related disruptions in the U.S. food industry. Nonetheless, the implementation of novel technological approaches must include consideration of previous efforts made by each food industry sector to improve efficiency and the financial investment necessary to implement

technological advances such as automation *(61, 77)*. Further studies are needed to determine the specific technological requirements across industry sectors in the U.S., the ability of food industry sectors to invest in new technologies, and the mechanisms by which these new advances could contribute to improving resilience in the industry.

Limitations

A major limitation of this needs assessment survey is the relatively low number of responses received and the associated potential selection bias, despite the engagement of a number of professional and trade organizations and the distribution of the survey via social media. The current widespread application of survey-based studies to understand various aspects of COVID-19 in the U.S. food industry *(30, 49, 58)* might have resulted in the industry's fatigue and increased reluctance to respond to surveys as the pandemic progresses, particularly given that our survey was distributed >1 year after the COVID-19 pandemic began.

Another major study limitation is that despite efforts to recruit more professional and trade organizations associated with the beef, pork, and poultry sectors, only one such organization agreed to distribute our needs assessment survey. We can only speculate about the possible reasons for the failure to engage more organizations associated with those sectors. Those sectors may have rightly grown more cautious as a result of the heavy toll the COVID-19 pandemic has inflicted on the U.S. meat industry, including in terms of infections, deaths, facility closures, and lawsuits *(27, 36, 65, 66, 76)*. Another reason for the limited engagement of those sectors may also be the fact that the study authors have stronger ties with the dairy and produce sectors, which were well represented in the survey. Because of the limited representation of the beef, pork, and poultry sectors in this study, further research is necessary to determine the generalizability of findings to those sectors. Although the survey could be repeated to get a better representation of the beef, pork, and poultry sectors, direct comparison with the results of the present study would not be possible, even if the same survey instrument were used, because of changes that have occurred in the epidemiology of COVID-19 and industry responses since the survey was closed in April 2021.

In line with the targeted recruitment efforts, responses were predominantly from individuals in high managerial positions (e.g., executives and facility managers), with only a few responses from individuals in nonmanagerial positions. Although this recruitment strategy potentially limited the range of perspectives included in the study, opinions and perceptions from individuals "at the top of the ladder" were targeted because they can provide valuable insight into facility and operation needs, challenges, decisions, and overall impacts of the COVID-19 pandemic in the U.S. food industry. However, this study did not include the complete spectrum of worker positions (particularly nonmanagerial) and therefore does not fully reflect food industry worker needs.

Every produce farm and food processing facility is unique and requires an approach to COVID-19 control tailored to their characteristics. However, apart from facility size and industry sector, we did not ask for the facility or operation characteristics and therefore cannot interpret whether a particular mitigation strategy in a particular facility or operation would be necessary, meaningful, or even possible. Because of the relatively small number of responses, more elaborate approaches to control for potential confounding of the associations between the outcomes and predictors of interest could not be conducted. Because Likert-item responses were considered interval or numerical data, assessment of associations were analyzed with nonparametric methods, which are less efficient than parametric methods for detecting existing effects.

The survey was open for participation for almost 3 months in early 2021, a period characterized by major changes in the U.S. response to the COVID-19 pandemic, such as the start of COVID-19 vaccination programs for essential non-health care workers. Some of those changes may have affected participants' responses depending on when they completed the survey and might not represent the needs of the U.S. food industry and the adoption of mitigation strategies early in the COVID-19 pandemic. Although open-ended questions allowed participants to comment about concerns regarding limited access to COVID-19 vaccines for food industry employees and their vaccination hesitancy, the survey did not include questions about vaccination because vaccines were not available at the time the pilot process was finished and the survey was initially distributed. Thus, a timely assessment of the food industry's needs regarding COVID-19 vaccination should be conducted.

Although questions about COVID-19 morbidity and mortality in the participants' facilities and operations could have provided valuable insights, we chose to exclude those questions to improve the survey completion rate. Similarly, we did not ask about the participants' perceptions of the effectiveness of mitigation strategies because without the context of facility or operation characteristics and data on COVID-19 epidemiology, interpretation of their perceptions would be limited.

CONCLUSIONS

Assuming that the responses of these survey participants are reflective of the wider U.S. food industry, the food industry facilities and operations in the U.S. are broadly prepared to protect their workers and businesses quickly and effectively in the event of a new SARS-CoV-2 variant or similar airborne pathogen. Future collaborations between the U.S. food industry and federal and state agencies to establish contingency plans and define appropriate training and the development of new technologies for automation and to support training in the food industry will be crucial in building resilience against future COVID-19–related and similar disturbances.

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SUPPLEMENTAL MATERIAL

Supplemental Materials A and B associated with this article can be found online at: https://doi.org/10.5281/zenodo.6584428

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