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Harnessing Sanitation Innovation Safely: A Pilot Study on Operators' Perceptions and Training When Adopting Superheated Steam in Food Processing Industries

ABSTRACT

Food workers play a crucial role in ensuring food safety. Implementing a novel sanitation technology requires providing workers with the tools and knowledge to feel comfortable using it. This study focuses on potential challenges in the adoption of superheated steam as surface sanitizer equipment for food processing industries. Superheated steam has emerged as a promising tool for dry sanitation. Because it works at temperatures ranging from 125°C to >300°C, evaluating worker safety hazards associated with its use is paramount. A trial with 24 participants was conducted. Participants received an in-person synchronous training presentation, operated a pilot unit, and provided feedback via survey. Results showed that 46% of participants considered the time and accuracy to operate the equipment as the biggest limitation, followed by its weight (42%). Almost half (42%) of the participants changed their perception of the technology after training. Active learning strategies used in this study could improve operational outcomes and knowledge transfer related to superheated steam technology and use because 83% of participants felt confident in explaining the technology to others. Our findings offer a perspective about the interconnected factors that influence the adoption of a technology that, if operated by trained personnel, could improve sanitation.

INTRODUCTION

Environmental sanitation in food manufacturing plants promotes food safety and product microbial quality *(11, 23)*. Various dry sanitation methods have been used in food plant surfaces, such as alcohol-based sanitizers, dry heat, hot oil, gaseous ozone, gaseous chlorine dioxide, and ultraviolet *(28, 30)*. However, challenges remain when approaching sanitation in low moisture food (LMF) facilities *(1, 9)*, such as those manufacturing nuts, nut butters, powdered infant formulas, and spices. For example, vegetative cells of some foodborne pathogens, as well as bacterial spores, are able to survive within dry processing environments and low-water-activity foods for long periods *(9)*. When moisture is introduced in food surfaces during cleaning activities, it can facilitate microbial growth; therefore, there is a need for inter-

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ventions to effectively control pathogen levels on surfaces and superheated steam has been proposed as a novel and promising solution for dry sanitation *(21, 28, 30)*. Superheated steam heats saturated steam at increasingly high temperatures (from 125°C to >300°C) while maintaining the same pressure *(13, 30)*. One of its most notable advantages is the large amount of latent heat that rapidly increases the surface temperature without steam condensation on the surface penetrating cavities and crevices *(5, 27)*, effectively inactivating pathogens without introducing moisture *(28)*. However, working with high temperatures creates risks to operators because superheated steam is typically invisible to the human eye *(10)* and accidental exposure may result in skin burns. Similarly, exposure to superheated steam on combustible materials may be a fire hazard, because inadequate cleaning may allow the formation of a powder or dust layer that can behave as a source of ignition when reaching 100–200°C *(42)*. For these reasons, this technology may present a risk to operators that needs to be addressed and understood before implementation in industry.

Food safety risks and occupational health are persistent challenges in food processing settings *(4, 15, 26)*. Food processing can involve significant safety, health, and ergonomics hazards. Occupational health and food safety risks can be considered interconnected factors in some cases; therefore, the development of policies and operational practices that consider and address both of these concepts is necessary *(26)*. Occupational accidents and illnesses result in a decrease of 4% in gross domestic product each year globally *(33)*; hence, workers' occupational health and safety are an essential issue *(18)*. The drive to strengthen standards in food quality and safety among processing industries is gaining interest worldwide *(26)*. The food processing industry has one of the poorest health and safety records within manufacturing *(15, 22, 32)*. According to Clayton et al. *(12)*, food sector representatives indicated that stakeholders appreciated the connection between food work and safety, yet only a few currently used this perspective in their work. Several factors have been identified that influence worker implementation of safe and effective sanitation practices. For example, a review by Medeiros et al. *(24)* mentioned that food workers that participated in a training detected obstacles to cleaning and sanitization, such as time constraints, lack of encouragement or willingness to adopt practices, and carelessness of managers and employees. Katsuro et al. *(19)* explained that it is important to empower, educate, and persuade food workers to exercise their powers in the protection of their occupational health and safety. Furthermore, the importance of integrating quality and health and safety management has been increasing among companies worldwide *(46)*, because these concepts are usually interconnected and influence overall performance. Our assessment of operators' safety perceptions of a sanitation tool that has the potential to enhance food safety will be of interest to stakeholders in food processing industry.

This study had two main objectives. The first objective involved developing training material about superheated steam safety to present to study participants, after evaluating the existence of official regulations and voluntary guidelines associated with the protection of the health and safety of food processing employees. In the second objective, we evaluated training participant ($n = 24$) safety perceptions of the superheated steam sanitizer equipment after providing hands-on experience with the technology and how certain training activities influenced their perceptions of safety at different times. The feedback was gathered in person via survey and compared with their experience in food industry and safety. The complete training incorporated active learning activities (ALAs), described as "instructional activities involving learners in doing things and thinking about what they are doing" *(2)*. Our hypothesis poses that trainings that incorporate both theoretical knowledge and hands-on experiential learning can provide positive results in incorporating a new technology.

MATERIALS AND METHODS

Presentation development and content design

Several sources of information regarding food workers' operational hazards potentially associated with superheated steam were evaluated. These sources included research papers, gray literature (i.e., statistics, standards), material from the equipment manufacturer *(6)*, and a deep search of the Occupational Safety and Health Administration (OSHA) guidance. OSHA's mission is "to promote safe working conditions by setting and enforcing standards and by providing training, outreach, education, and assistance" *(39)*. Experts from the Environmental Health and Safety Department at Cornell University were interviewed. The inclusion criteria for the selection of documents was that they should address one or more risks related to the equipment that was being used in the trial (e.g., high temperatures, heavy weight, etc.) and the mention of requirements of personal protection gear for specific risk-related tasks.

The findings from the literature review were used to develop an operator's safety training presentation for a superheated steam sanitizer technology. The presentation was designed to have a duration of 20–30 min, allowing additional minutes for questions and answers from the audience. The presentation was delivered using a synchronous, in-person format and a Microsoft® PowerPoint® slide deck (Microsoft 365 MSO, Version 2306; Microsoft Corporation, Redmond, WA). Contents covered an introduction of food safety challenges in food industries that cannot use wet sanitation practices and how superheated steam may aid in overcoming those challenges. In addition, key operator safety concepts (e.g., hazard symbols *(31)* and personal protective equipment [PPE] *(37)*) were included. Some examples of presentation slides are shown in *Figure 1*. The section of the training related to workers'

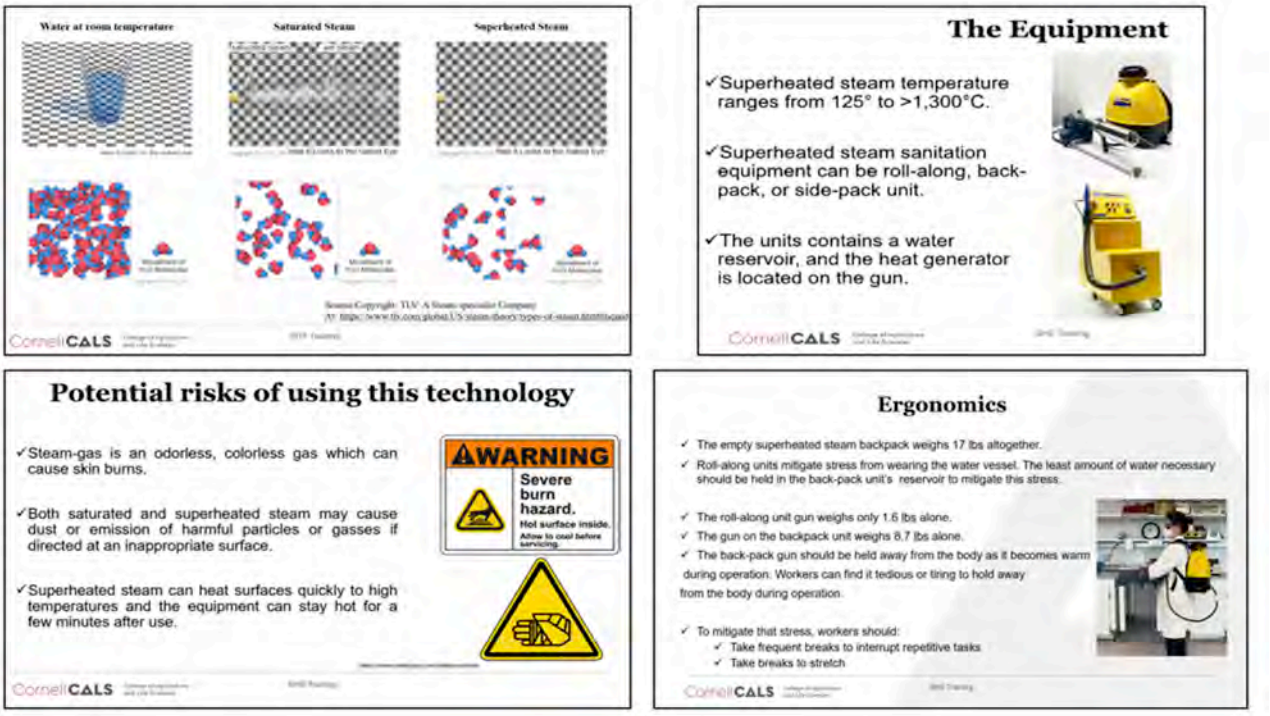

FIGURE 1. Examples of superheated steam safety presentation: (Top left) definition and live image of superheated steam with comparisons with other states of water; (Top right) types of superheated steam equipment; (Bottom left) potential risks of using the technology; (Bottom right) ergonomics of the use of the superheated steam equipment and weight considerations.

safety included a description of superheated steam, different types of superheated steam equipment, and potential risks of the technology (e.g., "superheated steam is an odorless, colorless gas which can cause skin burns"; "superheated steam may cause dust or emission of harmful particles or gasses if directed at an inappropriate surface"; among others). PPE requirements, operational guidelines, and ergonomic considerations were also described and shown to participants. Finally, a section on burn treatment strategies was included (e.g., skin burn severity levels and appropriate responses and burn treatments). Printouts were available as an additional tool for participants. The material is available online at https://blogs.cornell.edu/snyder/training-material/.

ALAs implemented in the training

During this experiment, training activities were designed so that participants experienced multiple ways of learning, including visual, auditive, and tactile actions. Examples of ALA strategies included experiential learning (i.e., learning and putting on all the PPE required for operation and mentioned in the presentation) and role playing (i.e., when using the superheated steam equipment on a surface). Theoretical concepts were explained in a scaffolded way via lecture (the term scaffolding designates the work an instructor does to help students comfortably execute a new task *(2)*). In addition to the theory included in the training presentation, participants handled the superheated steam machine in different circumstances, performing different actions such as turning the equipment on and off, carrying the backpack unit, and handling the portable gun, while wearing PPE. This simulated the situation that a food worker would experience during the sanitation process in their environments.

Throughout the training, other ALA concepts such as facilitating and amplifying were also incorporated. Facilitating entails the work of an instructor to help advance students' efforts while a task is underway *(2)*: amplifying refers to the work an instructor does to help students process, cement, and extend the learning outcomes of a task *(2)*. These two ALA steps are usually implemented by instructors to help students comfortably execute a new task. ALAs can benefit students in retention of knowledge, transfer of the knowledge to real-world contexts, and foster inclusivity *(2)*.

Survey development

A survey was designed using Qualtrics® software (Provo, UT). The survey instrument used was comprised of structured questions divided into two sections. The first section included demographic questions assessing age,

gender, experience in the food industry, and experience in food safety. The second section included qualitative and quantitative questions (e.g., multiple choice, rank, Likert scale) regarding the training, and safety perceptions of the superheated steam sanitizer system *(Table 1)*. The 10-point Likert scale (1 = likely and 10 = more likely) was included to evaluate the likelihood that employee safety concerns would limit the use of this technology. The question read as follows: "On a scale of 1 to 10, how much do you think employee safety concerns would limit the use of this technology?" The survey had three main goals: (1) to assess gained knowledge and awareness regarding the hazards associated with superheated steam and the safety measures required for its use, (2) to evaluate the participants perceptions of safety when operating the equipment, and (3) to identify any gaps or areas for improvement for this technology and sanitation equipment.

Participant recruitment

Participants were recruited with digital advertisements (i.e., flyer and recruitment email) disseminated through the Cornell email listserv consisting of students, faculty, and staff as well as through printed recruitment posters. Consent forms were provided to respondents before participation in the study, informing them of the purpose of the research, confidentiality and deidentification, and voluntary participation within the study. To comply with safety protocols, participants were informed about appropriate dress code to perform the trial and were provided appropriate PPE. The research protocol, which included the safety training and the survey tool, was reviewed and approved by the Institutional Review Board for Human Participants at Cornell University (IRB0147190).

Pilot training experiment and hands-on experience

The pilot training was conducted between March and June 2023 in a laboratory setting and included 24 participants divided in smaller groups of approximately 8 trainees per session. Participants were instructed to come to the trial with their hair secured and wearing long pants and long-sleeved shirts and closed-toed shoes (excluding fabric tennis shoes) for basic protection. They were equipped with thermal-resistant waterproof gloves, splash-proof lab goggles, and a properly fitting lab coat before starting the trial.

To simulate food worker's experience during the sanitation process with the superheated steam machine and to evaluate noise safety levels, the ambient noise generated was measured in a field evaluation. Each measurement was collected at different locations: the hearing zone of the operator and 3 ft (0.9 m) away from the operator. Table G-16 of the OSHA noise standard from the 29 CFR 1910.95(b) *(2)*) was used as a reference for establishing safe and unsafe noise levels *(36)*. Noise levels were measured using a QuestSoundPro sound level meter BHK050005 (Quest® SoundPro®, TSI Incorporated, MN).

During the training, respondents were briefed on their responsibility to regulate the application of the unit for microbial inactivation of a 12 × 12-in. (2.5 cm × 2.5-cm) surface, while maintaining safe operational conditions. This included determining treatment duration, maintaining a specified distance between the steam nozzle and the surface, and following specific tracing patterns on stainless steel surfaces. Respondents were also informed of their ability to pause the treatment for breaks if needed. The deidentified survey was provided to participants after the superheated stream safety training was completed. Deidentified data describe records that identifiable information removed or obscured so that the remaining information does not identify an individual *(35)*. The survey was filled out by participants, and researchers expressed their availability for clarification on ranked questions or open questions *(Table S2)*.

Data management and statistical analyses

Data were summarized with Excel 2019 (Microsoft). Descriptive statistics (mean, SDs, and percentages) were analyzed using Excel 2016 to obtain information regarding the demographics, the participants' perceptions of safety, and the ease of use of the superheated steam equipment, from the survey data. Paired *t*-tests and independent t-tests were also performed using this program and Jamovi 2.3 software available at https://www.jamovi.org/.

RESULTS AND DISCUSSION

Literature review findings and information included in operators' presentation

In total, 23 documents met the criteria for inclusion in this review and were evaluated for use in the training presentation content. No studies were found directly related to superheated steam and operators' personal safety. Similarly, there were no OSHA regulations specific to manual operation of superheated steam. The most applicable papers examined factors that could be extrapolated to superheated steam sanitation and operator safety. These studies explored *(Table S1)* burn severity on hot surfaces *(45)*, combustible dust dangers in dry food industries *(42)*, and ergonomics factors to prevent lower back pain due to the weight of the equipment *(44)*. They also offered insights into saturated steam sterilization *(13)* and standard designations for burns and the impact of contact time on burn severity *(3)*.

Although OSHA regulations for the manual operation of superheated steam were not found, relevant elements were identified in the 29 CFR 1910 General Industry Code and its subparts I and P *(39, 41)*. Within 1910 Subpart I were elements pertaining to PPE and 1910 Subpart P was related to Hand and Portable Powered Tools and Other Hand-Held Equipment. The OSHA General Duty Clause (1970), Section 5 - Duties, is applicable across all work environments beyond hazard-specific standards *(38)*. This section emphasized the requirement of each employer to furnish a

TABLE 1. Selected survey questions description presented after superheated steam safety training

Question	Possible responses	Results
What aspects of superheated steam technology do you consider the biggest limitations? (please rank these by numbering them from 1: most important, 4: least important)	❑ Employee safety ❑ Weight of equipment ❑ Amount of Personal Protective Equipment (PPE) needed to operate ❑ Time and accuracy required to operate	Time and accuracy required to operate: #1 (11), #2 (11), #3 (2), #4 (0). Weight of the equipment: #1 (7), #2 (10), #3 (5), #4 (2). Employee safety: #1 (6), #2 (3), #3 (13), #4 (2). Amount of PPE needed to operate: #1 (0), #2 (0), #3 (4), #4 (20). Rank #1: most important, #4: least important.
*How dangerous did you think this technology would be to use **before** participating in this trial?*	a. Very dangerous b. Dangerous c. Somewhat dangerous d. Not very dangerous e. Safe	a. Very dangerous (2) b. Dangerous (5) c. Somewhat dangerous (11) d. Not very dangerous (6) e. Safe (0)
*How dangerous did you think this technology would be to use **after reviewing** the safety training?*	a. Very dangerous b. Dangerous c. Somewhat dangerous d. Not very dangerous e. Safe	a. Very dangerous (1) b. Dangerous (6) c. Somewhat dangerous (9) d. Not very dangerous (7) e. Safe (1)
*How dangerous did you think this technology would be to use **after using** the technology?*	a. Very dangerous b. Dangerous c. Somewhat dangerous d. Not very dangerous e. Safe	a. Very dangerous (1) b. Dangerous (5) c. Somewhat dangerous (8) d. Not very dangerous (8) e. Safe (2)
Which drawbacks do you foresee for a food worker using this technology? (please rank them by numbering them 1: most important, 5: least important).	❑ Rushing the sanitation procedure ❑ Using the equipment the wrong way ❑ Using this technology on inappropriate surfaces ❑ Worker negligence or horseplay ❑ Not wearing appropriate personal protective equipment (PPE)	Rushing the sanitation procedure: #1 (17), #2 (5), #3 (0), #4 (2). Using the equipment the wrong way: #1 (1), #2 (14), #3 (5), #4 (2), #5 (2). Using the technology on inappropriate surfaces: #1 (2), #2 (1), #3 (12), #4 (5), #5 (4). Worker negligence or horseplay: #1 (3), #2 (3), #3 (6), #4 (6), #5 (6). Not wearing appropriate PPE: #1 (1), #2 (1), #3 (1), #4 (9), #5 (12) 1: most important, 5: least important
Please share your opinions about the superheated steam Employee safety training provided	a. Very helpful b. Helpful c. Somewhat helpful d. Not helpful	a. Very helpful: 70.8% b. Helpful: 29.2% c. Somewhat helpful: 0% d. Not helpful: 0%

Table continued on the next page.

TABLE 1. Selected survey questions description presented after superheated steam safety training (cont.)

Question	Possible responses	Results
How confident do you feel after participating in this exercise that you could explain to others how to use this tool?	a. Very confident b. Confident c. Fairly confident d. Not confident yet, but I will feel confident if I have the materials available to me to review several times. e. I could not explain how to use this equipment	a. Very confident: 45.8% b. Confident: 37.5% c. Fairly confident: 16.6% d. Not confident yet, but I will feel confident if I have the materials available to me to review several times: 0% e. I could not explain how to use this equipment: 0%
On a scale of 1-10, how much do you think employee safety concerns would limit the use of this technology? (being 1 – less likely and 10 more likely)	Range 1 to 10	Median: 5/ mean: 5.4 (SD±2.25) 2: 3 participants 3: 4 participants 4: 1 participant 5: 4 participants 6: 3 participants 7: 5 participants 8: 2 participants 9: 1 participant 10: 1 participant 1: less likely and 10: more likely
How much do you think that actually handling/using the equipment gave you a better sense of what it would be like to operate it?	a. A lot b. Some c. Not much d. None	a. A lot: 91.6% (22 participants) b. Some: 8.33% (2 participants) c. Not much: 0% d. None: 0%
If you have additional feedback about this sanitation technology, please share it with us. Thank you!		Table S2

place of employment free from recognized hazards that can cause harm to them. A compendium of OSHA legislation found pertinent to our study is summarized in *Table 2*. The ASTM International Standards *(3)* for heated system surface conditions that produce contact burn injuries (i.e., Designation C 1055 – 03-2014) were also reviewed, and ISO 15536-1:2006 was considered *(17)*.

A review of the superheated steam unit operator's manual and supplier's website included information on the equipment and its safe use *(6)*. This website had recommendations about operational practices around equipment voltage, pressure, maximum steam temperature, velocity of stream and dryer, and water capacity. On the manufacturer's website, some general safety recommendations were available. This included instruction to not point the nozzle at another person, pet, or flammable objects; the potential for severe burns; and the need to keep burn medications handy.

Recommended PPE

PPE is "equipment worn to minimize exposure to hazards (such as physical, chemical, mechanical, electrical), that cause serious workplace injuries and illnesses" *(37)*. Based on our review of the literature, PPE appropriate for superheated steam equipment operation includes industrial splash goggles, heat and waterproof gloves (e.g., gauntlets), long sleeves, and slip impact-resistant waterproof footwear *(37)*. Nitrile and latex gloves should not be worn under the heat-resistant gloves or by themselves because they can melt when exposed to superheated steam. Hair should be restrained to avoid contact with the superheated steam equipment . In addition, a heat-resistant and waterproof apron or smock is

TABLE 2. Summary of regulations and guidance applicable to superheated steam as a surface sanitizer

Applicable OSHA laws and regulations	Relevant sections applicable to superheated steam
1910 Subpart I	**Personal Protective Equipment**
1910.132	General requirements
1910.133	Eye and face requirements
1910.136	Foot protection
1910.138	Hand protection
1910 Subpart P	**Hand and Portable Powered Tools and Other Hand-Held Equipment**
1910.242	Hand and portable powered tools and equipment, general
1910.243	Guarding of portable powered tools
1910.244	Other portable tools and equipment
1910 Subpart G ***1910.95***	**Occupational noise exposure** Personal hearing protection must attenuate the occupational noise received by the employee's ears to within the levels specified in Table G-16 of 29 CFR 1910.95. For those employees with a standard threshold shift (STS), noise reduction must be sufficient to meet Table G-16a of 29 CFR 1910.95 (85 TWA).
OSHA Act of 1970 General Duty Clause ***Section 5 – Duties***	a. Each employer -- 1. shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees, b. shall comply with occupational safety and health standards promulgated under this Act. 2. Each employee shall comply with occupational safety and health standards and all rules, regulations, and orders issued pursuant to this Act which are applicable to his own actions and conduct.

recommended; this recommendation was made by Cornell Environmental Health and Safety experts. The evaluation of the superheated steam equipment revealed that the noise levels generated by the machine were not intense enough to require hearing protection as the employee operates the equipment approximately an arm's length away (85 dBA). Nevertheless, employees should be offered hearing protection if they wish to wear it as part of their PPE. If hearing protection is worn, a noise reduction rating of 29 dB or greater is recommended.

Demographic results and discussion

Of the 24 respondents (17 females [70%] and 7 males [30%]) that were recruited, 100% gave their consent to participate in the trial. The median age of respondents (n = 24) was 26 yr old (range, 21–38 yr). According to the U.S. Bureau of Labor Statistics, women represent 68.2% of the workforce in the food manufacturing and beverages industry *(34)*. This official percentage is similar to that of the present study. In total, 75% of the respondents had food industry experience and 70% had prior experience in food safety. Of the 24 participants, 58% (14) had both food industry and food safety experience. Experience in the food industry included holding positions as cooks, waiters, bartenders, and technicians in plants. Additional information about participants' food safety experience included learning about food safety concepts while working in the food industry and retail, taking food science courses, and obtaining Hazard Analysis and Critical Control Point and Safe Quality Foods certifications.

Because the intention to evaluate the superheated steam equipment was to conduct a preliminary study to understand

the use before widespread adoption, we acknowledge the limitation of having a sample that at the time of the study did not work in the food industry. Nevertheless, because several participants mentioned previously having positions such as cooks, waiters, and plant technicians, the results of this study could offer a close perspective to what a food worker might perceive when using the technology. Balanay et al. *(4)* also refer to the importance of risk reduction from workplace injuries and illnesses among college-aged students, particularly if they are working, if occupational health and safety (OHS) strategies are incorporated in the college curriculum, and more awareness of OHS resources are shared *(4)*.

Survey qualitative and quantitative results and discussion

Participants ranked four factors considering the biggest limitation of the superheated steam technology. Overall results showed that 46% of them considered the time and accuracy needed to operate the equipment as the biggest limitation, with a mean of 1.6 (±0.64 SD), on a rank of 1 to 4: 1 = most important to 4 = least important. This finding suggests that the participants anticipated that performing a thorough procedure would require a relatively high degree of attention and time to achieve successful microbial results. The weight of the equipment was ranked as the second biggest limitation by 42% of the respondents (mean, 2.1 ± 0.92). Of note is that the handheld portion (gun) of the equipment weighs 8.7 lb (3.9 kg) and the backpack unit (when empty) weighs 17 lb (7.7 kg). Furthermore, employee safety was selected as the third limitation, with a mean of 2.5 (±0.97 SD). The amount of PPE required to operate the equipment was not frequently identified as the biggest limitation, with a mean of 3.8 (±0.38 SD). This could indicate that participants did not perceive the quantity or usage ergonomics (e.g., comfortability) of the required PPEs to be a factor that limited their application of the technology. Among female participants, weight was ranked as the no. 1 biggest limitation in 41% (17) of the cases and time and accuracy in 25% (6) of the cases. None of the male participants ranked weight of the equipment first as the biggest limiting factor. These findings coincide with literature that found that some work-related activities (e.g., lifting, rack packing) are specified as only for male workers because of weight requirements *(22, 44)*. Furthermore, necessary changes such as process and equipment design and a minimum requirement to lift weights could be necessary *(22)* and a larger sample size of participants is recommended to support these findings.

Participants ranked five options regarding the drawbacks for a food worker using this technology. The majority of the respondents (69%) concluded that the drawback of highest importance was rushing the sanitation procedure (mean ± SD, 1.5 ± 0.88) on a rank of 1 to 5: 1 = most important to 5 = least important, followed by using the equipment the wrong way (2.6 ± 1). The drawback ranked as the least important by 50% of the respondents (4.3 ± 1) was not wearing appropriate PPE. Worker negligence and using the technology on inappropriate surfaces were ranked lower in importance, although these topics were specifically addressed in the safety training because to properly disinfect, surfaces first need to be clean and free of dust *(6, 42)*.

Participants provided perceptions of safety using a 5-point Likert scale, and their responses were evaluated at three different moments in the trial: (1) before and (2) after viewing the safety presentation and (3) after handling (using) the superheated steam equipment *(Table 3)*. Respondents were provided with a 5-point ranked question on the perceived level of danger associated with using the equipment at each point. No statistical significance ($P > 0.05$) was found based on gender ($P = 0.3$) or prior food industry experience ($P = 0.2$). Paired t-tests performed within the group ($n = 24$) before and after the training also showed no statistically significant differences; for example, before and after presentation training ($P = 0.2$) and before training and after presentation and handling the equipment ($P = 0.1$). Because this is a pilot study, conclusions derived from a statistical analysis can be limited due to the sample size. Before the trial, seven respondents believed that the technology was "very dangerous" or "dangerous," whereas six respondents thought that it was "not very dangerous" and no participant considered it "safe." After the hands-on trial of the technology, six respondents believed that the technology was either "very dangerous" or "dangerous," although there was an increased number of responses for "not dangerous" (8) or "safe" (2). Almost half of the participants changed their perceptions of the technology as a result of training, with five respondents viewing the technology as less dangerous after the training presentation and four respondents viewing the technology as less dangerous after handling the equipment. One participant viewed the technology as more dangerous after handling the equipment, which could be related to learning previously unknown risks of the technology *(16)*. Although the differences were not statistically significant, the changes to 10 participant' responses suggest that safety training could help mitigate concerns and enhance user confidence, alleviating preconceived concerns and building trust in the technology. Visschers and Siegrist *(43)* found increasing people's knowledge through communication and education is most likely to affect their perception of the hazard. Results for the 10-point Likert scale question showed that the median of the 24 responses had a rating of 5 and the mean was 5.4 (±2.25 SD). Half of participants thought that employee safety concerns were more likely to limit use of the technology, and half thought that employee safety concerns were less likely to limit the use of the technology *(Table 1)*. Eight responses skew toward the lowest values of the scale (range between 0 and 4 ranking), whereas 12 responses skew toward the higher end (range between 6 and 10 ranking).

TABLE 3. Participants' perceptions about levels of danger (from very dangerous to safe) before the trial, after watching the safety presentation, and after trying the technology

Survey question	Level of danger				
	Very dangerous	Dangerous	Somewhat dangerous	Not very dangerous	Safe
How dangerous did you think this technology would be to use *before participating in this trial?*	2	5	11	6	0
How dangerous did you think this technology would be to use *after viewing the safety training?*	1	6	9	7	1
How dangerous did you think this technology would be to use *after using the technology?*	1	5	8	8	2

Results related to ALAs indicated that the training was considered "very helpful" by 70% of the attendees and "helpful" for the remaining 30%. One participant indicated that the training content was helpful and emphasized important safety concepts, stating the following: "The safety instructions were very clear. I like that the most important aspect (where to hold and where to not touch) was repeated 3 times. No one could miss it even with limited attention. Thank you." This observation aligns with principles that Minnick et al. *(25)* stated in their study "the need for effective safety training and learning transfer is essential to be able to recognize risk, be aware of hazards, and to perform one's job with competence." In addition, survey results showed that all respondents (100%) agreed that handling the equipment surface sanitizer gave them a better sense of what it would be like to operate it and 83.3% felt confident in explaining the use of it to others *(Table 1)*. Open-response comments aligned with these findings. For example, one participant stated the following: "The training was helpful in terms of safety tips and operation instructions, but I felt more experience and practice will be needed before I can operate this device on my own confidently." These findings align with the OSHA definition of safety training found in Section 1910.155 - Subpart L, describing it as "the process of making proficient through instruction and hands-on practice in the operation of equipment, including protection equipment, that is expected to be used and in the performance of assigned duties" *(40)*. Our hypothesis about trainings that incorporate both knowledge-based and hands-on experiential learning being able to provide positive results coincide with what recent work by Fitzgerald et al. *(14)* who found that hands-on training and combinations of onsite or hands-on trainings with practical applications in food manufacturing plants are welcomed and preferred practices. The tailored active learning strategies applied in the training, such as (1) discussions during the lecture presentation, (2) hands-on experience handling the equipment surface sanitizer and wearing PPE, and (3) role playing as a potential user could have enhanced the acquisition of knowledge by respondents *(2, 8)*. Furthermore, hands-on training may help minimize errors and enhance the overall effectiveness and safety of the superheated steam technology *(40)*.

Finally, participants were asked for their general feedback about any part of the trial. Of 24 participants surveyed, 15 (63%) of them decided to include their comments in this section. The most frequent comments were related to the weight of the steam gun (five comments), the long period of time needed to operate the tool effectively (six comments), and the invisibility of the steam (three comments). These comments align with the ranked questions results from the survey discussed in previously. Of note, all of the participants had no prior experience with superheated steam, potentially signaling a general uneasiness and uncertainty about effective sanitization with an invisible thermal technology that requires manual operation. All individual comments are summarized in *Table S2*.

Food safety implications and the use of superheated steam technology

The use of superheated steam as a novel sanitation method in food facilities, especially those manufacturing LMF, presents promising opportunities for enhancing food safety through better sanitation results, as research has widely shown *(5, 21, 28, 30)*. Its ability to rapidly increase surface temperature without introducing moisture can effectively control pathogen transmission, thereby

addressing a significant challenge in such manufacturing environments. Nevertheless, the adoption of this technology brings potential risks, primarily to operators' occupational health and safety. Therefore, the implications of using this technology need to be carefully considered. Although it offers an effective solution to sanitation challenges in LMF facilities, its implementation requires stringent safety measures to protect operators from burns and prevent fire hazards. Addressing these risks requires comprehensive training and education for food industry workers. Empowering them with knowledge about the technology, its risks, and safety protocols is essential for ensuring their occupational health and safety. For said reasons, the development of a safety training presentation involving concepts about the risks of the technology, how it works, and what elements are needed to successfully operate the equipment was crucial for the research team. To provide an additional training tool, rooted in the concept of active learning, the inclusion of several physical elements (e.g., PPE, equipment, etc.) to safeguard operator's wellbeing was a priority. Furthermore, incorporating feedback from workers into the development and implementation of safety protocols can enhance their effectiveness and acceptance among stakeholders. Latest trends to achieve competitive advantages and obtain sustainable development in industries include the implementation of an integrated quality, environmental and occupational health, and safety management approach. Our work presents a unique example of this perspective.

CONCLUSIONS

This research can serve as a starting point for different stakeholders that are currently in the search for an alternative method of dry sanitation and who are considering superheated steam. This promising technology has several advantages, such as effective microbial reduction *(20, 30)*, sustainability regarding water use *(28)*, and no need for chemicals *(29)*; therefore, it presents an opportunity to expand the current options of surface sanitizers for food industries. Because of its innate features, for example, high temperature and invisibility, implementing this technology requires providing workers with the necessary equipment and knowledge to feel comfortable and empowered to use it. The results of this pilot study provide insight into the importance of conducting the necessary steps before incorporating a new technology that will be handled by operators that have no preexisting knowledge about it. Assessing operators' perceptions of safety and incorporating applicable training situations might be beneficial to the learning experience and knowledge transfer, based on our results. Our findings may further aid superheated steam equipment surface sanitizer manufacturers to improve their products by showing the potential concerns of users. Opportunities for designing the superheated steam equipment to be more ergonomically friendly to users, especially regarding its weight, could also be considered. Investing in training programs using ALAs as well as addressing the importance of food safety and the connection to a safe work environment could improve overall performance. Addressing these interconnected factors can lead to successful and efficient implementation, thereby improving food safety outcomes in the industry.

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