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Sanitary Carcass Dressing and Food Safety Practices in South Central U.S. Small and Very Small Establishments Manufacturing Fresh and Not-Ready-to-Eat Pork Products

ABSTRACT

Small and Very Small meat harvest and products processing establishments warrant unique consideration with respect to development and utilization of food safety interventions. While industry best practices have been developed for the sanitary manufacture of beef products, similar practices are lacking for U.S. pork products manufacturers. To assist development of best practices for Small and Very Small pork slaughter and further processing establishments, a survey instrument asking for information on establishment and facility characteristics as well as current sanitary practices was distributed to establishments in the Southwest U.S. to gauge current industry practices and identify areas in need for improvement for food safety protection. Nineteen facilities returned fully or partially completed questionnaires, detailing use of antimicrobial interventions on pork carcasses or further processed not-ready-to-eat (NRTE) products, as well as sanitation schedules, selected sanitizers used during facility sanitation, employee hygienic practices, training, handling of raw versus finished product, and the frequencies and organisms (indicators, pathogens) sampled for during routine microbiological sampling programs. Findings from this survey will be useful for the development and dissemination of industry best practices to assist Small and Very Small pork harvest and NRTE products manufacturers.

INTRODUCTION

Consumption of pork products contaminated with microbial pathogens by improper handling and/or preparation of intact or non-intact pork products may lead to human disease. Painter et al. *(28)* determined that for cases of foodborne illnesses involving consumption of red meat products, 9.8% involved the consumption of pork cross-contaminated with one or more bacterial pathogens.

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Bacterial pathogens associated with not ready-to-eat (NRTE) and RTE pork products include the non-typhoidal salmonellae, *Staphylococcus aureus*, *Campylobacter* spp., *Yersinia enterocolitica*, and *Listeria monocytogenes (11, 16)*. The Pathogen Reduction; Hazard Analysis Critical Control Point (PR/HACCP) Systems Final Rule, published in 1996 by the U.S. Department of Agriculture Food Safety and Inspection Service (FSIS), established pathogen reduction performance standards for *Salmonella* in inspected meat and poultry products *(37)*. For market hog carcasses, no more than 6 positive *Salmonella* samples per set of 55 are allowed *(36)*. Recent microbiological baseline studies have reported that post-harvest *Salmonella* prevalence on market hog carcasses has fallen to 1.66% *(40)*. Nevertheless, toxin-producing *E. coli* (STEC), *Toxoplasma gondii*, methicillin-resistant *Staphylococcus aureus* (MRSA), *Y. enterocolitica*, and microbiological indicators (aerobes, *Enterobacteriaceae*, *E. coli*, and coliforms) are currently being evaluated on pork carcasses and cuts for prevalence and in some cases, quantities and identities *(48)*.

Of the approximately 6,000 federally inspected meat and poultry processing facilities, 78.5% are classified as Small or Very Small *(20)*. Consequently, special attention has been given to the food safety practices of these establishments. In 2006, FSIS issued its Strategic Implementation Plan for Strengthening Small and Very Small Plant Outreach to increase establishments' access to food safety and regulatory compliance resources, technical assistance, education, and training *(38)*. Additionally, FSIS maintains a "Small and Very Small Plant Outreach" page on its website, with information and resources developed specifically for Small and Very Small establishments *(49)*. However, Small and Very Small meat and poultry processors face financial obstacles to the implementation of food safety practices and interventions requiring large capital investment. Boland et al. *(8)* determined that FSIS estimates of costs for total HACCP system implementation for Small plants in the great plains region were 3.87 to 4.42 times greater than those reported by surveyed establishments. This would indicate that the costs of food safety systems implementation likely limits the attractiveness of complex antimicrobial interventions requiring substantial capital investment, facility renovation, or hiring of highly trained individuals capable of overseeing intervention use during processing. A survey of U.S. meat and poultry slaughter and processing establishments found that smaller plants invested less in capital-intensive food safety technologies than larger plants, opting instead to invest in labor-intensive food safety measures in sanitation and operations *(17)*. Large establishments, in contrast, may employ a multi-hurdle approach designed to produce desired cumulative reduction in pathogen loads on carcasses and products. Thus, it is critical to develop and disseminate information to smaller facilities detailing the implementation and use of sanitary animal slaughter and carcass handling procedures.

According to the U.S. Government Accountability Office (GAO) *(35)*, the development of best practices involves identifying organizations that are widely recognized for major improvements in their performance and efficiency in a specific area; the processes, practices, and systems identified in these organizations are referred to as best practices and provide a model for other organizations with similar missions. Best practices developed for Small and Very Small establishments producing NRTE pork products should provide practical, science-based information to assist establishments in improving food safety systems. The objective of this study was to survey Small and Very Small inspected facilities producing NRTE pork products with regard to their current food safety and sanitation practices in order to determine needs by this sector of the pork industry and apply findings toward development of food safety recommendations to protect the microbiological safety of fresh pork products.

MATERIALS AND METHODS

Survey of Small and Very Small pork slaughter and processing establishments

A multi-component, multi-question survey assessing the sanitary processing practices of pork slaughter and processing establishments was adapted from a similar instrument developed and shared by J. N. Sofos, Dept. of Animal Sciences, Colorado State University, Fort Collins, CO. The survey instrument and supporting documents were evaluated by the Texas A&M University Institutional Review Board (IRB; No. 2017–0234), and it was determined that the research did not constitute human subjects research. Dillman's Tailored Design Method was used to collect data in this study, using mailed paper questionnaires that *(13)* were mailed via the U.S. Postal Service to 131 Small and Very Small establishments engaged in pork slaughter and/or not ready-to-eat (NRTE) products manufacture in Texas, Oklahoma and surrounding states. Establishments eligible to participate were identified through the Texas Association of Meat Processors (TAMP) directory and the FSIS Meat, Poultry and Egg Product Inspection Directory *(42)*. A postage-paid return envelope was included in the survey packet, as well as a cover letter describing the research objectives, intended use of responses, measures to maintain respondent anonymity with respect to data reporting, and contact information for study investigators *(13)*. Also included were instructions for completing and returning the survey instrument. Following a 6-week response period after initial distribution of the packets, a second invitation (complete with questionnaire and return envelope) was mailed to non-responding facilities.

Information requested included establishment processing and product manufacturing data, plant layout, sanitation practices, food safety interventions and food safety verification procedures utilized by the establishment. Surveys were coded with a three-digit identification code unique to each plant in order to blind responses from participating surveys to data entry personnel. Participating establishments were not identified by USDA-FSIS establishment identification numbers. Survey responses were entered into a database to facilitate statistical analyses of responses. Data were analyzed using Microsoft® US Excel® for Mac v.15 (Redmond, CA).

Dillman et al. *(13)* identified four sources of error in survey research: coverage error, sampling error, nonresponse error, and measurement error, each of which should be addressed and limited to acceptable levels when conducting survey research. Coverage error occurs when the population frame fails to include all subjects in the population of interest. An attempt to reduce coverage error was made by using both the Texas Association of Meat Processors (TAMP) directory and the FSIS Meat, Poultry and Egg Product Inspection Directory. Sampling error occurs when some, but not all, of the members of the population frame are included in the study. To reduce sampling error, all processors identified as Small and Very Small establishments engaging in pork slaughter and/or processing were invited to participate in the study. Measurement error is contained within the instrument and "occurs when respondents are unable and unwilling to provide accurate answers" *(13)*. Every attempt was made to incorporate valid, reliable, and unambiguous questions in the survey instrument by adapting the survey instrument previously used with other types of NRTE meat products. Additionally, the instrument was reviewed by a panel of experts for content and face validity prior to distribution. Non-response error occurs any time less than 100% response rates are obtained and can be a threat to external validity *(22)* should non-respondents differ from respondents in surveyed characteristics. A total of 19 usable responses were obtained, resulting in a 14.5% response rate. Early and late respondents were compared to address nonresponse error *(2, 22, 27)*. Late responders were defined as those who responded to the follow-up questionnaire *(22)*. No significant differences were found between early and late responders.

RESULTS AND DISCUSSION

Establishments' production and facility characteristics that potentially impact product microbiological safety

Because of the low response rate, data analysis was limited to summary statistics. Across all responding facilities, the mean annual pork production volume was 2.64 million lb. (range: 20,000 to 10 million lb.). More than two-thirds (68.4%; 13/19) of establishments reported producing some type of sausage, including fresh, smoked, skinless, and/or summer sausage. Over half (57.9%) reported producing cooked or smoked product(s), while 42.1% (8/19) reported producing retail pork cuts *(Table 1)*. The most common products produced by respondents were sausage, cooked or smoked products, and retail fresh cuts. Food safety recommendations for Small and Very Small pork harvest and further processors should thus provide recommendations for both sets of activities (harvest and fresh products cutting as well as further processing) for maximal industry utility. The average facility physical area for responding establishments (n = 15) was 12,232 + 14,419 ft^2 (range: 600 to 50,000 ft^2), including non-processing areas (office, access hallways, product and ingredient/materials storage areas). The average facility age was 42.4 years (range: 2.0 to 85.0 years; n =

TABLE 1. Fresh and not-ready-to-eat pork products produced by responding small and very small pork processing establishments (n = 19)[a]

	% Respondents Producing Product Type	
Products	***n***	**%**
Sausage	13	68.4
Cooked or smoked products	11	57.9
Retail cuts	8	42.1
Ham	3	15.8
Bacon	3	15.8
Custom pork	2	10.5
Boudain	1	5.3
Pork carcasses	1	5.3

[a]Respondents were afforded opportunity to indicate all product classes manufactured; data are presented as percentage of respondents producing a specific product type.

18) (data not shown). Seven establishments reported their facility age was > 50 years, while four reported the facility was built within the last 15 years. Twelve of 19 (63.2%) establishments reported having completed construction in the past five years to expand or renovate processing areas (data not shown). Renovations were described to facilitate greater food safety preservation during production through changing surface materials (e.g., incorporating smooth, cleanable and easily sanitized surfaces: steel, flooring materials, etc.), or incorporation of processing systems likely to enhance food safety through microbial control (e.g., carcass scalding, refrigeration/freezing upgrades).

FSIS Directive 6410.3 *(41)* identified maintaining positive pressure airflow as a means to maintain sanitary process control procedures in poultry, though such systems may also be applied to pork products manufacture. In the current study, one-third of responding facilities (33.3%; 6/18) reported positive airflow was utilized in their finished product room, whereas 12/18 (66.7%) reported having no airflow control system *(Table 2)*. Approximately 79% (15/19) of establishments reported having a temperature-controlled environment in their facility; 21% reported their facility was not temperature-controlled *(Table 2)*. When probed regarding the locations of temperature-controlled areas/environments within establishments, respondents consistently indicated that no temperature control systems were maintained in areas designated for animal slaughter because of inability to maintain adequate temperature control with outside air exposure. *Table 3* provides mean reported temperatures for different locations within respondent facilities. Fresh product cutting areas and further processed post-lethality product handling areas should be temperature controlled to prevent microbiological organisms from replicating, in addition to having sanitation systems designed to minimize movements of pathogens from these product handling areas *(9, 34, 39, 43, 44)*.

Employee hygiene management practices and procedures

Regarding training for employees on proper handwashing as a component of Good Manufacturing Practices (GMPs), 89.5% (17/19) of respondents indicated that all company employees were provided handwashing training. In one facility, only supervisors were described as receiving handwashing training, one facility, reported not providing any training to employees regarding handwashing practices (data not shown). Additionally, almost half of respondents (47.4%; 9/19) indicated that supervisors were responsible for monitoring employee handwashing practices, and the remainder (10/19) indicated that employees assumed personal responsibility for adequate handwashing practices (data not shown). *Table 4* depicts findings from survey questions regarding establishment employee dress code

TABLE 2. Facility physical characteristics potentially impacting product safety: airflow management, product handling water sources, employee handwashing stations location(s), and floor drain locations

Facility Characteristic[a]	Response	*n*	%
Airflow Control System Utilization?	Positive Airflow Used	6/18	33.3
	Negative Airflow Used	0/18	0.0
	No Airflow Control	12/18	66.7
Temperature Control in Processing?	Yes	15/19	78.9
	No	4/19	21.1
Water Source(s)[b]	Municipal	15/18	83.3
	Private Source(s)	1/18	5.6
	Well/Other Sources	2/18	11.1
Hand-Washing Station Location(s)	Inside Raw and/or Finished Product Processing Areas	18/19	94.7
	At Entry/Exit of Processing Area(s)	5/19	26.3
	Employee-Accessible Restrooms	1/19	5.2

[a]Facility characteristics indicate questions posed to respondents followed by the number of surveys returned with responses given to question.

[b]Reports water source characteristics for waters specific to meat harvest and/or products manufacture.

TABLE 3. Environmental temperatures (°C) for pork products manufacture, excluding slaughter and office areas within facilities

Facility Area/Operation	Mean ± S.D.[a]	Minimum	Maximum
Carcass chiller/locker	2.1 ± 4.5	-5.6	10.0
Product packaging/manufacturing	8.3 ± 4.5	1.1	20.0
Finished product chilled storage	-2.2 ± 8.6	-28.9	3.9
Product transportation cooler	6.2 ± 8.5	-3.9	13.3

[a]S.D.: Values given are means from one respondent-provided temperature datum (per respondent) ± one sample standard deviation.

TABLE 4. Respondent employee clothing/dress practices and requirements potentially impacting food safety (n = 19)[a]

Protective Clothing/Dress Item	Raw Products Handling Required		Processed/Finished Products Handling Required	
	n	%	*n*	%
Apron/Frock/Smock	17	89.5	13	68.4
Hair Net, Beard Net	14	73.7	14	73.7
Plastic Gloves (Latex, Nitrile, Vinyl)	12	63.2	10	52.6

Frequency of Clothing Items Change during Operations[b]

Once/Day-Beginning of Operation		Multiple Times/Day		As Needed/Soiled	
n	%	*n*	%	*n*	%
7	36.8	6	31.6	11	57.9

[a]Values given are percentages of returned surveys indicating a required dress item (*n*/*N*).
[b]Values given are percentages of returned surveys indicating the frequency of clothing item changes; respondents were allowed to affirm simultaneous use of multiple practices. Percentages may not sum to 100.0%.

requirements during operations. When asked about requirements for employee dress during operations, 100% of respondents affirmed that the company maintained appropriate dress requirements for employees. With respect to harvest and fabrication of raw products, most respondents required the use of aprons while working. Fewer (13/18 responding facilities) reported requiring apron use in handling of processed product compared with those requiring that employees wear aprons for raw product production *(Table 4)*. Similarly, 73.7% respondents reported requiring employees to wear hair and/or beard nets during operations. Only 12/19 (63.2%) of facilities reported requiring gloves as a cross-contamination barrier during production or raw materials handling. Similarly, only 10/19 (52.6%) of respondents required employees to wear gloves for handling of processed products. The majority of respondents indicated that clothing items (aprons/frocks/smocks), gloves and hair, and/or beard nets were changed at least daily; laundered/new disposable items were donned at the beginning of the work shift or changed on an as-needed basis. In addition, four establishments indicated company policy was to require employees to don cleaned or new protective clothing articles daily at the start of operations but to obtain a new article of clothing during his/her shift if the article became soiled (data not shown).

In addition to employee dress and personal protective equipment (PPE) requirements, 42.1% (8/19) of establishments reported use of sanitizing footbaths to prevent spread of microbial cross-contamination by foot and/or forklift traffic *(Table 5)*. For respondents indicating use of sanitizing

TABLE 5. Respondent sanitizing footbath usage, sanitizer chemistries utilized within footbaths, and replacement schedules (n = 8)

Sanitizer Type[a]	Respondents Using	Replacement Frequency by Sanitizer Type	
	n	%	
Footbath: Quaternary Ammonium Compound-Liquid	6	75.0	Every 2 weeks – Twice per year
Footbath: Chlorine (HOCl, OCl-)	3	37.5	Every 2 weeks – Every 3 months
Footbath: Ammonium Chloride	1	12.5	Daily
Dry QAC Crystal	5	62.5	Daily – Twice per year
Foaming Sanitizer	3	37.5	As needed

[a]Some respondents indicated the use of both dry sanitizer crystal and liquid footbaths, or footbaths and foaming boot sanitizers. Values may not sum to 100%.

footbaths in processed products manufacture, 7/8 establishments reported that footbaths were located at all entries into finished product handling areas. When asked to identify the types of footbath sanitizing agent(s) used, 75.0% (6/8) indicated use of a liquid quaternary ammonium chloride (QAC)-containing solution *(Table 5)*. Three facilities reporting the use of a QAC in sanitizing footbaths also reported the use of chlorine as a sanitizing agent in footbaths. Reported rotation schedules in responding facilities varied from daily to two times per year *(Table 5)*. In contrast to footbath usage, seven establishments reported using a foaming-type boot decontamination system or a dry antimicrobial boot decontamination system to protect against cross-contamination.

The USDA-FSIS has endorsed the use of multiple sanitizers for employee footwear decontamination, along with a sanitizer rotation program to help prevent microbial pathogens from adapting to a particular sanitizer *(45, 46)*. More than 40% of establishments reported use of sanitizing footbaths to control contamination by foot traffic. Multiple respondents indicated using multiple types of sanitizers in their facilities; QACs were the most frequently reported type of sanitizer used by responding establishments. Suslow and Harris *(32)* recommended against chlorine-type sanitizers use because of rapid inactivation in the presence of organic matter, recommending instead the use of iodophors or QACs. Footbath sanitizing solutions should be maintained at concentrations adequate to (i) inactivate microbial pathogens on employee footwear, and (ii) prevent the footbath from harboring microbial pathogens *(25, 26)*. In addition to footbath usage, several establishments (37.5%) reported using entryway foaming systems, and 62.5% indicated use of dry/crystalline sanitizers in addition to footbaths. Foam disinfectants can be sprayed onto floors as employees or equipment such as carts or forklifts enter or exit an area *(25)*. Dry antimicrobial floor treatments in powder or crystalline form can be applied to floors or used in place of sanitizing solutions in footbaths. Use of these systems is recommended to prevent microbial pathogen transfer between different areas of a plant as well as to prevent entry of pathogens from outside the plant into the harvest or further processing environments.

Facility cleaning and sanitation systems, frequency, and sanitizer usage/rotation

When asked about facility cleaning and sanitation activities and employee responsibilities, 10.5% (2/19) of responding establishments reported that specific employees are assigned to facility cleaning and sanitizing duties only, while a majority of respondents (52.6%; 10/19) reported that employees assigned to cleaning and sanitizing duties also had production responsibilities (data not shown). More than one-fourth (26.3%; 5/19) of responding facilities stated that employees are responsible for cleaning and sanitizing their own workspace, while 10.5% reported use of an outside contractor for cleaning and sanitizing (data not shown).

Figure 1 depicts frequencies of cleaning and sanitation activities of facilities for differing surface types (e.g., food contact surfaces, non-contact surfaces, walls/floors, etc.). Across surface types, chlorine-type sanitizers were the most frequently utilized sanitizer type for facilities, including for product contact surfaces, with QAC-type sanitizers the second most frequently utilized *(Table 6)*. All respondents indicated that equipment was routinely cleaned by hand, following partial or full disassembly before cleaning and sanitizing. Peracids (peracetate in combination with peroctanoate) were utilized in two establishments, while acidified sodium chlorite and hot water (180°F) were reported to be used for surface sanitation in one facility each *(Table 6)*. The majority (10/19) of establishments reported using multiple sanitizers, principally QAC and chlorine-type sanitizers (data not shown).

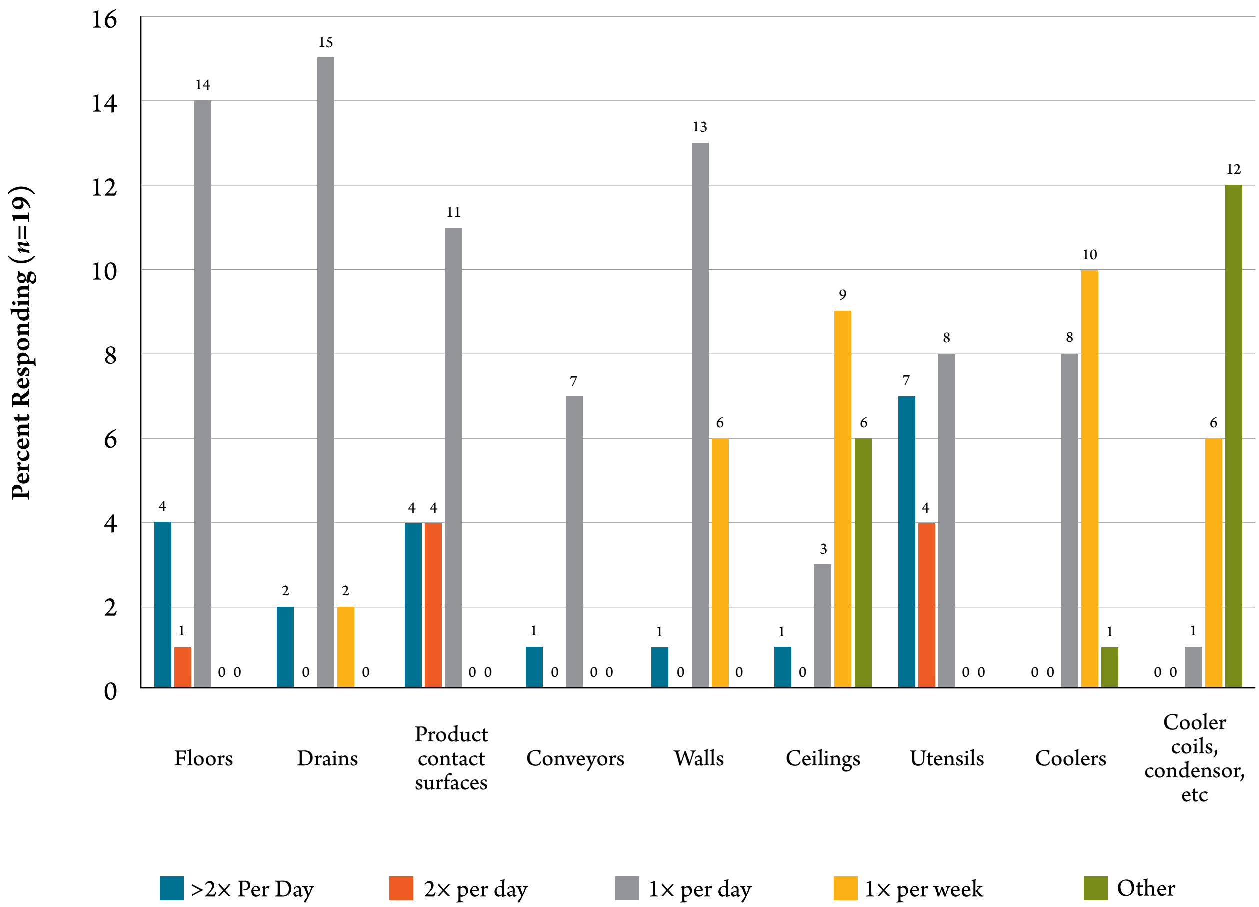

FIGURE 6. Frequencies reported (count of respondents indicating) of facility cleaning and sanitation activities for food contact and non-contact surfaces.

TABLE 6. Sanitizer classes utilized for sanitizing of facility surfaces reported by respondents, by surface type

Sanitizer Class	Usage by Site (% of facilities using indicated sanitizer class) (*n*)		
	Floors (n = 19)	Floor Drains (n = 19)	Product Contact Surfaces (n = 18)
Chlorine[c]	89.5% (17)	94.7 (18)	77.8 (14)
QAC[a]	68.4 (13)	63.2 (12)	61.1 (11)
Peracid[b]	10.5 (2)	10.5 (2)	11.1 (2)
ASC	5.3% (1)	5.3% (1)	5.6 (1)
180 °F Water	5.3% (1)	5.3% (1)	5.6 (1)

[a]QAC: quaternary ammonium compound. ASC: Acidified sodium chlorite.
[b]Includes peracetic acid and peroctanoic acid sanitizers.
[c]Includes hypochlorite salts, chlorine dioxide (aq.; gas), and other chlorine-type sanitizers (excluding acidified sodium chlorite).

Mikel and Newman *(26)* reported that QACs, chlorine, hot water (minimum 180°F) and iodophors are most commonly utilized in pork harvest and in the manufacture of pork products in the U.S. These researchers recommended facilities implement sanitizer rotation programs to prevent microbial pathogens and/or spoilage organisms being present in the harvest or manufacturing environment as the result of developing sanitizer tolerance. Marriott and Gravani *(25)* described chlorine sanitizers as a generally very effective sanitizer choice when applied onto effectively cleaned surfaces at recommended pH and concentration, although iodophors and QACs were also described as equally useful for microbial control.

Food safety interventions applied during pork harvest, fabrication, and further processing

Pork harvest is initiated by animal stunning and slaughter by exsanguination. Pearce et al. *(29)* observed aerobic microbe counts to be highest immediately after exsanguination, reporting approximately 6.0 $\log_{10}$ CFU/cm^2 each on the ham, belly, and neck. Bolton et al. *(9)* identified a need for sanitation of stick knives between animals and cutting out around the stick location to prevent translocation of skin-contaminating pathogens to deeper tissues. Taormina and Dorsa *(33)* recommended that knives be cleaned and dipped in hot water (82°C; 179.6°F) for >15 sec to achieve meaningful reductions in aerobic bacteria and pathogens between carcasses. In a typical swine slaughter process, the skin is not immediately removed following stunning and exsanguination. The carcass is scalded and dehaired, singed and polished/shaved, and possibly washed prior to evisceration *(44)*. Nonetheless, cross-contamination of swine carcasses is still a concern, with increases in numbers of aerobic and coliform bacteria in carcasses that were polished before evisceration as compared to those that were singed *(29)*. Warriner et al. *(52)* demonstrated *E. coli* cross-contamination between pork carcasses and between carcasses and the harvest environment. *E. coli* isolated from equipment used in scraping and dry polishing were also isolated from a band saw and a butcher's hands, demonstrating microbe transmission through the harvest environment during pork carcass harvest. Such evidence of cross-contamination highlights the importance of controlling and reducing pathogen contamination throughout slaughter.

Antimicrobial interventions are decontamination treatments applied to reduce contamination with microbes, including microbial pathogens. Physical interventions applied to carcasses include hot water washing or steam application, or knife trimming. Chemical interventions are varied and may be applied at several points, such as pre-evisceration or prior to entering the cooler *(23, 50)*. Ten of 11 (90.9%) facilities harvesting pork, when asked about the use of antimicrobial interventions on skin-on carcasses, indicated that antimicrobial interventions were not utilized. One facility affirmed the use of a hide-on antimicrobial intervention, described as a water wash, although water temperature and pressure/volume parameters were not provided (data not shown). Over half (54.5%; 6/11) of responding facilities completing pork harvest indicated using one or multiple antimicrobial interventions to carcasses pre-fabrication; 50% of these reported the use of an acidified sodium chlorite (ASC) intervention, 50% a lactic acid application, 17% a vinegar and water mixture, and 17% a water wash (some respondents indicated use of multiple sequential interventions).

Van Netten *(51)* reported achieving a 2.9 $\log_{10}$ CFU/cm^2 reduction of S. Typhimurium on inoculated pork carcasses by applying 2% lactic acid at 55°C for 60 sec. Epling et al. *(14)* observed decreased *Campylobacter* and *Salmonella* spp. recoveries at 5 min and 24 h post-mortem from pork carcasses that had been sprayed with 2% lactic acid. Rodriguez *(31)* examined the effects of using a sanitizing spray system designed for Small and Very Small slaughterhouses; the system applied a 2% lactic acid solution at 55°C and achieved a 1.9 $\log_{10}$ CFU/100 cm^2 reduction on pork carcasses. Biemuller et al. *(7)* observed a 4.0 $\log_{10}$-unit reduction in aerobic bacteria counts and decreased *S.* Enteritidis prevalence on pork carcasses through use of acetic acid sprays at pH 1.5 and 2.0. Carpenter et al. *(10)*, however, reported achieving reductions in *Salmonella* serovars of only 0.7 $\log_{10}$ CFU/cm^2 by the application of 2% acetic acid to inoculated pork bellies. Researchers applying acetic:propionic (3:2) acid blends to pork carcasses reported reductions in aerobic plate counts (APCs) from 0.8 to 1.5 $\log_{10}$ CFU/cm^2 *(30)*. Hamilton et al. *(19)* likewise reported reduced prevalence of *E. coli* (92.9% for control versus 12.5% for treated carcasses) on carcasses treated with ASC (pH 2.5 + 0.1) for 15 sec in two medium and large Australian abattoirs.

A pork carcass may be subsequently fabricated into intact and/or non-intact NRTE products. More than one-third (36.4%; 4/11) of responding facilities reported performing an antimicrobial intervention during fabrication. Three facilities reported application of ASC, while the remaining facility utilized lactic acid. The majority of responding facilities (10/11; 90.9%) indicated that no antimicrobial interventions were used on fabricated products prior to packaging (data not shown). One facility responded that a topical sprayed ASC intervention was applied to fabricated products prior to chilling; intervention pH and temperature information was, however, not provided. The extent of microbial cross-contamination during fabrication is a function of the extent of contamination on incoming carcasses and raw materials, as well as the sanitary condition of the fabrication environment *(1, 3)*. *L. monocytogenes* was recovered from equipment in a pork cutting room (50% of sampled sites positive), with recovered isolates reportedly capable of biofilm formation *(21)*. Gomes-Neves et al. *(18)* determined that meat cutters contribute to *Salmonella* cross-contamination on fresh pork. Delhalle et al. *(12)* reported concentrations of *E. coli*/coliforms ranging from 0.2 to 1.2 $\log_{10}$ CFU/g on fresh pork cuts from Belgian meat plants. Mann et al. *(24)* validated time and temperature combinations that prevented *Salmonella* growth during cold storage, reporting no increase of *Salmonella* in pork cuts or ground pork held below 4.4°C for 72 h, or in ground pork held at 10 and 7.2°C for 24 and 32 h, respectively. Smaller processors conducting fabrication operations at non-refrigeration temperatures must ensure that fabricated and processed product is moved to cold storage as quickly as possible to limit microbial growth.

Pork carcass and product chilling is critical to inhibiting bacterial growth. Nonetheless, nearly the same number of establishments reported storage of finished products alongside raw products in facility refrigeration areas (9/19; 47.4%) as reported that raw and finished products were not stored alongside one another (10/19; 52.6%). Pork carcasses should be chilled rapidly, ideally to below 4°C surface temperature within 0.5 to 2 h. The FSIS has recommended that coolers be capable of lowering carcass internal temperatures to 4.4°C within 24 h of the carcass being moved into the cooler *(44)*. Bolton et al. *(9)* reported increases (0.7 to 0.9 $\log_{10}$ CFU/cm^2) in total viable counts ($P < 0.05$) during chilling of post-eviscerated, washed carcasses. These and other researchers have indicated that several parameters of chilling, including air temperature and humidity, air velocity, carcass ingoing temperature, and spacing between carcasses, should be controlled to maximize chilling rate so as to obtain the greatest microbial growth inhibition, and may be executed as a CCP within a HACCP plan *(9, 34)*. The U.S. Food and Drug Administration (FDA) considers many fresh meat items, including fresh cut pork and some cured and uncured sausages, as requiring time/temperature control for food safety, in alignment with USDA-FSIS-recommended procedures for sanitary production of these products *(15, 37, 38)*. Best practices for the storage of fresh beef products and further processed ingredients directs processors to account for the storage of fresh/raw meat and non-meat ingredients versus finished product storage, indicating that finished products not in final packaging should be separately stored from carcasses and fresh products *(4)*. Pork processors producing NRTE products should provide systems to prevent/reduce such cross-contamination between carcasses or fabricated cuts, and further processed pork products, whenever possible.

Microbiological sampling for carcasses and finished products

The incorporation of routine carcass and/or product microbiological sampling has been described for beef safety management as an effective food safety systems component, through the assessment of microbiological hygiene status of carcasses as well as the identification of harvest/process environment sanitary conditions *(6)*. Such testing assists in the development of microbiological baselines, thus allowing companies to apply testing data to determining process control *(5)*. Only two of 19 (10.5%) respondents indicated that carcasses were routinely sampled for human pathogens or indicator organisms; these establishments reported sampling for *E. coli* and *Listeria*, although, frequencies of carcass sampling were not provided. A slightly higher number of facilities (3/19) reported regular sampling of finished products for microbial pathogens and/or indicator organisms (data not shown). Pathogenic and indicator organisms sampled for by respondents included *L. monocytogenes, Salmonella*, and *E. coli*. In all cases, respondents identified non-detectable (< 1 CFU/sample) as the acceptable outcome of pathogen testing for finished products. Only one facility detailed corrective actions for non-conforming finished product microbiological sampling results: re-cooking of product or product condemnation/destruction. The number of facilities engaged in finished product sampling that reported using company personnel and facilities for microbiological sample analysis was equal to the number of those contracting a third-party firm (17.6%; 3/17). The majority of firms (57.9%; 11/19) did not indicate that finished product testing was applicable to their firm's operations, or chose not to provide information (data not shown).

In a microbiological baseline assessment of pre-evisceration and post-chilled pork carcasses, USDA-FSIS reported *Salmonella* prevalence of 1.66%, whereas generic *E. coli* were detected on 96% and 12% of pre-evisceration and post-chill carcasses, respectively *(40)*. Thus, Small and Very Small establishments conducting testing for pathogens may utilize testing for indicator organisms to determine the antimicrobial impacts of food safety interventions. Routine testing for microbiological organisms (indicators, pathogens) may be useful for allowing establishments to verify process control to regulatory agency officers *(41)*. Additionally, although only a small number of respondents indicated testing for *L. monocytogenes* on finished product, USDA has recommended that *Salmonella* testing be utilized when conditions warrant such data collection in Small and Very Small facilities producing RTE products. Such recommendations could be applied to manufacturers of NRTE further processed pork products as well, to determine process control or impacts of processing and/or interventions on finished product safety *(43)*.

CONCLUSIONS

In April 2015, FSIS released guidance designed to assist small meat and poultry plants to meet validation requirements of Title 9 of the Code of Federal Regulations (CFR) §417.4 *(47)*. FSIS noted that some establishments had not completed adequate initial validation with respect to translating the critical operating parameters (COPs) from scientific and technical resources used in HACCP plans to validate interventions and prerequisite programs. Establishments were directed to engage in ongoing verification by use of in-plant data to demonstrate understanding of COPs and capacity of the process to produce a product with the intended degree of safety. FSIS routinely identifies the practices and procedures within compliance guidance documents promulgated to the U.S. meat and poultry industries as being designed for implementation by all members of the U.S. meat and poultry industries, including Small and Very Small establishments. Needs remain for the development of simple-to-apply antimicrobial interventions and sanitary procedures in order to improve the microbiological safety of NRTE pork products. Industry best practices documents can provide useful information to Small and Very Small establishment personnel regarding sanitary dressing of animal carcasses, hygienic fabrication practices, useful antimicrobial interventions effective against pathogens of concern, and recommended methods for process facility cleaning and sanitation during non-operational periods. Data reported in this document can help to direct the development of industry best practices recommendations for the sanitary harvest and manufacture of fresh pork and further processed NRTE pork products.

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