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Foods: science, engineering and technology

Characterization of decontamination procedure of beef carcasses at slaughterhouses in the province of Antioquia, Colombia

Caracterización del procedimiento de lavado y desinfección de canales bovinas en las plantas de beneficio animal del departamento de Antioquia, Colombia

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Abstract

Background: Beef slaughterhouses must use a carcass decontamination procedure to control pathogens and thus prevent foodborne diseases transmitted by meat.

Objectives: This study aimed to characterize beef carcass decontamination procedures at slaughterhouses located in the province of Antioquia (Colombia). All the slaughterhouses were open, registered, and approved by Invima (Instituto Nacional de Vigilancia de Medicamentos y Alimentos in Spanish) at the time of the study.

Methods: This descriptive study collected information from 23 beef slaughterhouses between July 2019 and April 2021 through documentary reviews and visits to slaughterhouses, using forms and questionnaires.

Results: The study allowed the characterization of the procedures used to decontaminate beef carcasses, showing that the chemical disinfection of the carcasses is used to control microorganisms in at least 73.9% of the slaughterhouses analyzed. According to secondary sources, it was found that most of the slaughterhouses are small (slaughter volume <50,000 heads per year); 10 of them use citric acid, lactic acid, peracetic acid, and a mixture of organic acids in concentrations between 900 and 1,200 ppm, 1.5 and 1.7%, 180 and 190 ppm, and 900 and 1,200 ppm, respectively, as carcass disinfectants and according to the technical data

sheet of the product. During the visits and through the application of the questionnaire, it was found that the 12 slaughterhouses had implemented chemical disinfection which is not scientifically based, using manual devices as an intervention method to control pathogenic microorganisms. It was found that the type of company, slaughter volume, and the lack of financial resources are the determining factors in the selection of decontamination procedures. The validation of the beef carcass decontamination procedures in the different slaughterhouses in the study was demonstrated.
Conclusions: Although it was established that at least one decontamination procedure, such as chemical disinfection, is used in the slaughterhouses of study, this option is not supported by scientific or technical evidence. The findings support the need for improvements in the slaughterhouses of the province of Antioquia, including the improvement of surveillance programs to reduce pathogens in the meat chain effectively.
Keywords: Beef carcass, Carcass decontamination, Processing interventions, Organic Acids.

Resumen
Antecedentes: Las plantas de beneficio animal deben utilizar un procedimiento de descontaminación de canales para el control de patógenos y con ello, prevenir la aparición de enfermedades transmitidas por el consumo de carne.
Objetivos: El objetivo de este estudio fue caracterizar el procedimiento de descontaminación de canales bovinas en las plantas de beneficio animal del Departamento de Antioquia, Colombia, que se encontraban abiertas, inscritas y autorizadas por el Invima al momento del estudio.
Métodos: Este estudio descriptivo recolectó información de 23 plantas de beneficio animal de la especie bovina, a partir de revisiones documentales y visitas a las plantas, usando formatos y cuestionarios entre julio de 2019 y abril de 2021.
Resultados: El estudio permitió caracterizar los procedimientos y técnicas de descontaminación de canales bovinas, revelando que en al menos el 73,9% de las plantas de beneficio estudiadas se realiza la desinfección química de las canales para el control de microorganismos. A partir de fuentes secundarias, se encontró que la mayoría de las plantas de beneficio animal en el Departamento de Antioquia son muy pequeñas, 10 de ellas utilizan productos de desinfección de canales, tales como el ácido cítrico, ácido láctico, ácido peracético y mezcla de ácidos orgánicos en concentraciones entre 900 y 1200 ppm, 1,5 y 1,7%, 180 y 190 ppm y 900 y 1200 ppm, respectivamente; y estos son utilizados de acuerdo con las recomendaciones de la respectiva ficha técnica del producto. Por otro lado, durante la visita a las plantas de beneficio y mediante la aplicación del cuestionario, se constató que las 12 plantas visitadas han implementado la desinfección química como método de intervención para el control de microorganismos patógenos, realizando su aplicación mediante dispositivos manuales, no obstante, estas prácticas no están fundamentadas científicamente. Por otro lado, se estableció que aparentemente el tipo de empresa, volumen de sacrificio y falta de recursos financieros son los factores que determinan la elección del procedimiento de descontaminación de canales. De igual manera, se evidenció la necesidad de realizar estudios para validar la efectividad del procedimiento de descontaminación en las diferentes plantas de beneficio.
Conclusiones: Aunque se estableció que en las plantas de beneficio animal visitadas se implementa al menos una técnica de intervención como la desinfección química, esta

elección no tiene un sustento con base a fundamentos científicos y técnicos. Estos hallazgos respaldan la necesidad de mejoras en las plantas de beneficio animal del Departamento, incluyendo mejoras al programa de vigilancia de la reducción efectiva de patógenos en la cadena cárnica.
Palabras clave: Canales de res, Descontaminación de canales, Intervenciones de procesamiento, Ácidos orgánicos.

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Introduction

Food of animal origin is a relevant source of foodborne diseases; among them, meat is one of the main food vehicles for biological hazards to humans (1). Due to its physical and chemical characteristics, meat can favor the growth of pathogenic microorganisms such as *Salmonella* spp., *Escherichia coli* O157:H7, and other potential foodborne disease carriers or related toxins, which makes meat a food of major risk to public health (2, 3, 4) and for which its handling requires adequate safety practices. Indeed, it has been estimated that 14.8% of foodborne disease outbreaks in Colombia were caused by consuming meat and meat products (5).

Microbial contamination of meat can occur during the slaughter process, which inevitably takes place in transforming live animals into meat. Most of this contamination comes from dirt, dust, and feces associated with the animal's skin, which encounters the carcass when removed (6, 7).

Several decontamination methods have been reported to reduce the microbial contamination of carcasses: physical (e.g., hot water, steam, steam vacuuming), chemical (e.g., organic acids, chlorine, acidified sodium chlorite, polyphosphates), and biological (e.g., bacteriophages, bacteriocins) (8). However, the most effective carcass decontamination techniques are nonbiological, with chemicals, acids, steam, and hot water washes being the most effective (1).

Chemical decontamination involves the application of a chemical substance at some point during slaughter. The most commonly used and extensively studied substances for chemical decontamination of carcasses are low molecular weight organic acids (e.g., lactic, acetic, citric, fumaric) and other chemicals such as chlorine, acidified sodium chlorite, peroxyacids, and trisodium phosphate (8).

Several studies worldwide, including two Colombian studies, have investigated the effect of chemical decontamination and bacterial reduction of beef carcasses (9, 10, 11, 12, 13).

Nevertheless, the characterization of decontamination procedures of beef carcasses in abattoirs is scarce, with few studies characterizing these procedures among other food safety practices (14, 15). This lack of reliable information on decontamination procedures of beef carcasses in any country constrains the possibilities for evaluation and improvement, which represents a risk of contamination of meat with pathogenic microorganisms of public health concern (16). In addition, this undesirable contaminated meat also affects productivity (17)

since the ineffectiveness of microbiological risk control leads to commercial and economic disadvantages for slaughterhouses (17,18). The decontamination process chosen by the slaughterhouse to guarantee meat safety and reduce the risk of biological hazards must be validated according to government regulations and their preferred methods under specific production conditions and circumstances (8, 19,20).
In 2019, the Colombian cattle slaughter was 3,407,750 heads, of which 96.4% were intended for national consumption. Of this number, the province of Antioquia provided the highest proportion, with 541,003 heads (15.88%) (21), making the decontamination characterization procedure highly relevant in this province to reduce the risk of contamination with pathogenic microorganisms of public health concern. Therefore, this study aimed to characterize the decontamination procedures of beef carcasses in slaughterhouses located in the province of Antioquia (Colombia).

Materials and methods

Ethical considerations

This study has the approval of the Committee for Animal Experimentation (Act Nr. 133, June 2th, 2020) and of the Committee of Bioethical of the University Research Headquarters (CBE-SIU) (Act Nr. 20-110-905, June 26th, 2020). Both committees of the Universidad de Antioquia, Colombia.

Type and study design

A descriptive study was conducted to characterize beef carcass decontamination procedures (Fig. 1). The characterization of beef carcass decontamination procedures was carried out in the 23 slaughterhouses registered and authorized by Invima in the province of Antioquia. Both primary (i.e., the information provided by the slaughterhouses themselves and by direct observation of the researchers during a visit) and secondary sources (i.e., the information provided by the Invima) were used. Several strategies were implemented to increase the likelihood of voluntary participation in cattle slaughterhouses. Information on the legal representative of the slaughterhouse (including email and telephone contact numbers in the Invima database and on the commercial pages) was collected to establish the initial contact. The abattoirs were then contacted by email through an invitation letter, and later phone calls were made to confirm the email arrival. Twelve cattle slaughterhouses agreed to participate and were finally enrolled in the study.

Documentary review from the Invima´s repository

Documentary information registered, authorized, and available in the Territorial Working Group (TWG) Occidente 1 repository, through informed consent, were collected and reviewed to identify the characteristics of each cattle slaughterhouse. For this purpose, a form was designed to collect general, socio-cultural, and technical information and for the characteristics of the decontamination procedures.

Visits to the slaughterhouse

A single visit was carried out between November 2020 and April 2021 to each of the 12 cattle slaughterhouses that agreed to participate in the study. During the visit, the characterization information of each slaughterhouse was collected through a questionnaire completed by the delegated and responsible person who attended the visit.

The questionnaire included five sections: 1) general information, 2) socio-cultural information, 3) technical information, 4) characteristics of the disinfection process, and 5) verification of the decontamination procedure. In addition, an open non-cooperative observation (22) of the routine decontamination procedure of carcasses was carried out during the same visit, using a form to record this specific information.

Pre-test of the information collection instruments

All information collection instruments —questionnaires and forms, were pre-tested at a small scale to evaluate their effectiveness. In each case (i.e., documentary review from the Invima´s TWG Occidente 1 repository, characterization information of each slaughterhouse during the visit, and characterization of the routine decontamination procedure during the visit). Six experts in the field (one doctor of engineering and five veterinarians with long experience in beef abattoirs and postgraduate studies in the field of veterinary public health) evaluated the structure to ensure that all important issues were identified and covered, and to identify problems, such as unnecessary length, poorly worded, unclear questions, or allowance of subjective responses (23) (Figure 1).

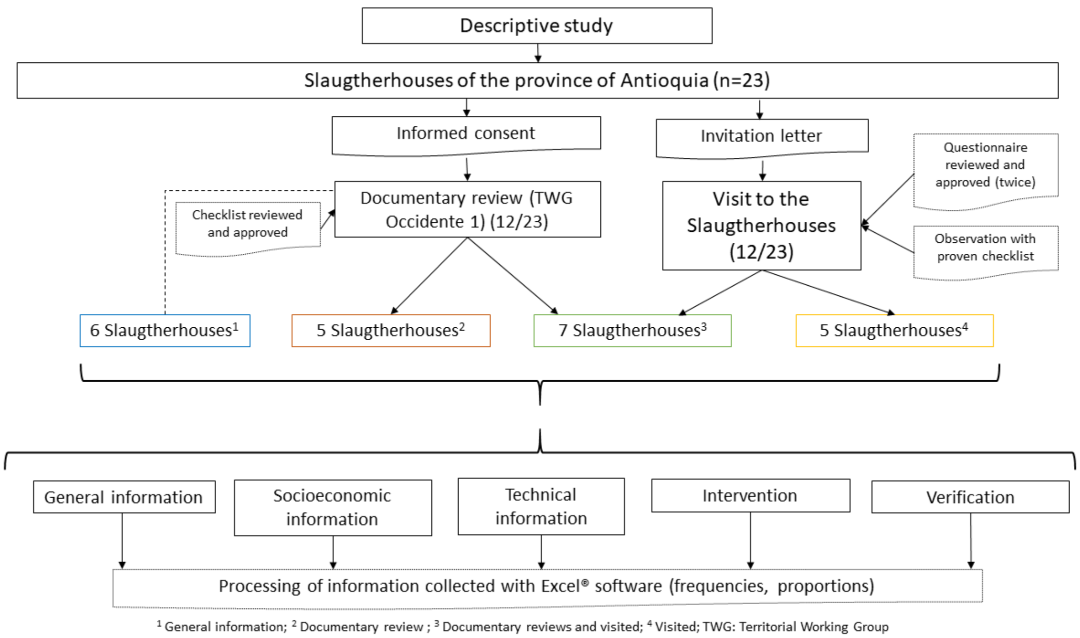

Figure 1. General information on the study design for the characterization of beef carcass decontamination procedure at slaughterhouse in the province of Antioquia (Colombia), 2019-2021.

Statistical analysis

For the processing of the information collected from the different sources, a database was built in Excel® software (Redmond, Washington, USA). Subsequently, the information was analyzed to estimate frequencies and proportions.

Results

General characteristics of the slaughterhouses

According to the Invima repository, 23 cattle slaughterhouses in Antioquia were active and authorized during the evaluation period (July 2019 and April 2021). Seventeen paid for the permanent inspection service. Five conducted periodic inspections, and information was not obtained from one slaughterhouse because it was registered in another jurisdiction (i.e., Caribbean Coast-2 TWG). According to the origin of the working capital (type of company), 11 public, eight private, and four mixed slaughterhouses are in Antioquia. Following the sanitary authorization, five slaughterhouses can allocate their products for self-consumption, seven at the local level, nine at the national level, and only one has the authorization to export. In general, it was identified that most slaughterhouses have a slaughter volume of <50,000 heads per year (monthly average-based) (Table 1).

Table 1. Information of the slaughterhouses registered, open, and with sanitary authorization by Invima in the province of Antioquia (Colombia), 2019-2021

Slaughterhouse	Municipality	State of operation	Inspected by	Type of inspection	Type of company[7]	Destination of the carcass	Slaughter volume[8]	Enrolled and visited during the study
1	Amalfi	Open	TWG Occidente 1[2]	Not permanent	Mixed	Self-consumption	<50,000	Yes
2	Amagá	Open	TWG Occidente 1	Permanent	Private	National	<50,000	No
3	Andes*	Closed[1]	TWG Occidente 1	Permanent	Public	Local	<50,000	No
4	Anorí	Open	TWG Occidente 1	Not permanent	Public	Self-consumption	N.D.	No
5	Cañasgordas*	Open	TWG Occidente 1	Permanent	Public	National	<50,000	Yes
6	Caramanta*	Open	TWG Occidente 1	Permanent	Private	Local	<50,000	Yes
7	Caucasia	Open	Caribbean-2 Coast TWG	N.D.	Private	N.D.	N.D.	No
8	Ciudad Bolívar*	Open	TWG Occidente 1	Permanent	Mixed	National	<50,000	No
9	Copacabana	Open	TWG Occidente 1	Permanent	Public	Local	<50,000	No
10	Ebéjico	Open	TWG Occidente 1	Not permanent	Public	Self-consumption	N.D.	No

11	Fredonia	Open [3]	TWG Occidente 1	Permanent	Public	Local	<50,000	Yes
12	Marinilla*	Open	TWG Occidente 1	Permanent	Private	National	<50,000	No
13	Medellín*	Open	TWG Occidente 1	Permanent	Mixed	National	<100,000	No
14	Peque	Open	TWG Occidente 1	Not permanent	Public	Self-consumption	<50,000	Yes [9]
15	Puerto triunfo	Open [4]	TWG Occidente 1	Permanent	Public	Local	N.D.	No
16	Rionegro*	Open	TWG Occidente 1	Permanent	Mixed	National	<50,000	Yes
17	San Carlos	Open [5]	TWG Occidente 1	Not permanent	Public	Self-consumption	<50,000	Yes
18	San Roque*	Open	TWG Occidente 1	Permanent	Private	National	<50,000	Yes
19	Santa Rosa de Osos*[6]	Open	TWG Occidente 1	Permanent	Private	National and export	Between 50,000 and 100,000	No
20	Sonsón*	Open	TWG Occidente 1	Permanent	Private	National	<50,000	Yes
21	Turbo*	Open	TWG Occidente 1	Permanent	Private	National	<50,000	Yes
22	Urrao	Open	TWG Occidente 1	Permanent	Private	Local	<50,000	Yes
23	Yarumal*	Open	TWG Occidente 1	Permanent	Private	Local	<50,000	Yes

[1]Closed since November 2020; [2]TWG: Territorial Working Group; [3]Open since March 2020; [4]Open since November 2020; [5]Open since July 2020; [6]Slaugtherhouse with

authorization to allocate carcasses for export and the only beef slaughterhouse in Antioquia with Hazard Analysis Critical Control Point (HACCP) certification by Invima; [7]According to the origin of the working capital; [8] Heads per year (monthly average-based); [9] Through virtual means; *Slaughterhouse subject to review of the beef carcass decontamination procedures in 2019, according to the TWG Occidente 1; N.D.: No data.

Documentary characterization of the beef carcass decontamination procedure

A 52.17% (12/23) of the slaughterhouses in the study had information on the decontamination procedures, identifying some sociocultural and technical features. Six slaughterhouses had personnel trained to perform the decontamination procedures, and 10 used carcass disinfection products. In the latter case, five plants used citric acid, two used lactic acid, the other two used peracetic acid, and one used a mixture of organic acids. It was evidenced that 66.67% of the slaughterhouses (8/12) used carcass disinfection products according to the product's technical data sheet, but only two used it in an adequate concentration for the intended purpose and consistent with scientific publications (18,33). It was also found that eight slaughterhouses had a documented carcass decontamination procedure; however, in six of these procedures, corrective actions were described when a non-conformity of the disinfectant solution was evidenced. Finally, eight slaughterhouses had a verification record of the microbiological results of the decontamination procedure (Table 2).

Table 2. Information registered in the Invima´s Territorial Working Group (TWG) Occidente 1 on the beef carcass Washing and Disinfection (decontamination) procedures in 12 slaughterhouses located in the province of Antioquia (Colombia), 2019-2021

Slaughterhouse	The educational level of the person responsible for the quality area	Personnel trained to conduct the decontamination procedure	Chemical product used	Use of disinfection products according to the product's technical data sheet	Use of a decontamination product according to scientific publications	Documented decontamination procedure	Documented decontamination procedure, describing corrective actions when non-compliance is evidenced	Record of the verification of microbiological results of the decontamination procedure
1	Professional, DVM[1]	No	Citric acid	No	No	No	No	No
2	N.D.	No	None	No	No	No	No	No
3	Professional, DVM[1]	No	Citric acid	Yes	No	Yes	Yes	No
4	Technologist, FQC[2]	Yes	Peracetic acid	Yes	Yes	Yes	Yes	Yes
5	Technologist, F[3]	No	Citric acid	Yes	No	Yes	No	Yes
6	Professional, DVM[1]	Yes	Citric acid	Yes	No	Yes	Yes	Yes
7	Professional, DVM[1]	Yes	Organic acids	No	No	Yes	Yes	Yes
8	Technologist, F[3]	Yes	NA	NA	NA	NA	NA	Yes
9	N.D.	Yes	Citric acid	Yes	No	Yes	Yes	Yes

10	Professional, IE[4]	No	Citric acid	Yes	No	No	No	Yes
11	N.D.	Yes	Citric acid	Yes	No	Yes	Yes	Yes
12	Professional, DVM[1]	No	Peracetic acid	Yes	Yes	Yes	No	No

[1]DVM: Veterinarian; [2]FQC: Food Quality Control; [3]F: Foods; [4]Industrial Engineer; N.D.: No data; NA: Not applicable (the information recorded by the TWG was related to the general decontamination program).

Characterization of the carcass Washing and Disinfection (decontamination) procedure

Twelve out of the 23 slaughterhouses allowed the visit; however, these 12 establishments differed from the 12 for which a record of information related to the carcass decontamination process was found during the documentary review of the TWG Occidente 1 records. Seven slaughterhouses were consistent with the information collected during the face-to-face visit and the documentary review from the TWG (Fig. 1).

Ten of the 12 slaughterhouses had a documented carcass decontamination procedure. In addition, it was evidenced that the 12 slaughterhouses visited had implemented chemical intervention in the process of obtaining carcass meat as a method to control pathogenic microorganisms. Regarding the chemical products used, it was identified that four slaughterhouses applied citric acid in concentrations of 0.10-0.15% (1000-1500 ppm), three of them used lactic acid in concentrations of 1.2-2% (12,000-20,000 ppm), three other slaughterhouses applied peracetic acid in concentrations of 160-210 ppm, and two used organic acid mixtures in concentrations of 0.02-0.12% (200-1200 ppm). In addition, eight of the 12 slaughterhouses used carcass disinfectants according to the product's technical data sheet but did no provided scientific support for the implemented procedure; therefore, no carcass decontamination procedure has been properly validated to date. Concerning the microbiological verification of the process, the study showed that nine of the 12 slaughterhouses sampled were positive for generic *E. coli* (indicator microorganism) and *Salmonella* spp. (pathogenic microorganism) (Table 3).

Table 3. Characterization of the carcass Washing and Disinfection (decontamination) procedure in the 12 slaughterhouses of study, located in the province of Antioquia (Colombia), 2019-2021

Slaughterhouse	Municipality	QD	The educational level of the personnel responsible for quality	DP of decontamination	Chemical product used	Concentration (%)	Application of the disinfectant according to TS	Scientific support of the IP	Use of the decontamination product according to scientific publications	Microbiological verification of the decontamination procedure
1	Amalfi	No	NA	Yes	Citric acid	0.10	Yes	No	No	No
2	Cañasgordas	Yes	Technologist	Yes	Citric acid	0.15	Yes	No	No	Yes
3	Caramanta	No	NA	Yes	Citric acid	0.15	Yes	No	No	Yes
4	Fredonia	Yes	Technician	Yes	Organic acids	0.12	No*	No	No	Yes
5	Peque	Yes	Professional	Yes	Lactic acid*	1.45	No*	No	Yes	No
6	Rionegro	Yes	Technologist	No	Peracetic acid	0.02	Yes	No	Yes	Yes
7	San Carlos	Yes	Bachelor	Yes	Organic acids	0.02	No*	No	No	No
8	San Roque	Yes	Technologist	Yes	Citric acid	0.13	Yes	No	No	Yes
9	Sonsón	Yes	Technologist	Yes	Lactic acid	1.21	Yes	No	Yes	Yes
10	Turbo	Yes	Technologist	Yes	Peracetic acid	0.02	No*	No	Yes	Yes
11	Urrao	Yes	Professional	No	Lactic acid	2.02	Yes	No	Yes	Yes
12	Yarumal	Yes	Professional	Yes	Peracetic acid	0.02	Yes	No	Yes	Yes

QD: Quality Department; DP: Documented Procedure; TS: Technical Sheet; IP: Implemented Procedure; NA: Not applicable; * slaughterhouse does not present a technical sheet of the disinfectant.

On the other hand, the direct observation of the decontamination procedure during the visit allowed us to identify that the 12 visited slaughterhouses implemented this process; nevertheless, none of the slaughterhouses recognized the combination of methods or the multiple obstacles strategy, and none had implemented the Hazard Analysis Critical Control Points (HACCP) safety assurance system. From a quality point of view, it was identified that seven slaughterhouses carried out prior verification of the disinfectant concentration and monitored the concentration during the workday or shift. Regarding the technique or mode of application of the disinfectant, it was observed that all the slaughterhouses applied the disinfectant by spraying with manually operated devices, five slaughterhouses had an exclusive operator for the carcass decontamination procedure, one slaughterhouse knew the pressure of the equipment used for the application of the disinfectant solution, and none of them knew the applied volume of disinfectant solution per carcass. When reviewing the documentation of the slaughterhouses visited, it was found that six had the documented procedure to carry out the carcass decontamination, evidencing a lower number of slaughterhouses than initially indicated such procedure when the questionnaire was applied during the visit. Four slaughterhouses were also identified to perform the carcass decontamination activities described in the documented procedures; therefore, the decontamination procedures need to be correctly validated, according to the results. However, seven slaughterhouses have laboratory records of microbiological results of the carcasses.

Factors determining the selection of the Washing and Disinfection (decontamination) procedure.

Based on the information collection instruments —both from primary and secondary sources, and what was observed during the visit, the factors that determined the selection of the carcass decontamination procedure in the slaughterhouses of the study were the type of company, slaughter volume, and lack of financial resources.

Discussion

The current study characterized the beef carcass decontamination procedures routinely used in slaughterhouses. The response rate obtained was lower (52%) when compared to similar studies using comparable methodologies (14, 15). Although several efforts were made to increase the response, the voluntary participation in the research and some pre-existing prejudice against sharing information on safety procedures with academia led to the response rate obtained.

The five slaughterhouses that did not have a permanent official inspection could get access to this critical inspection service provided by territorial entities taking advantage of the regulations and guidelines issued by the Ministry of Health and Social Protection (24, 25) similar to the inspection system of other countries, such as Mexico, USA, and Canada, with federal and state inspection (14, 26, 27, 28). Some authors have suggested a relationship between the reduction in the prevalence of pathogens in the final product and access to an official inspection, resulting in microbiologically safer carcasses (26).

More than 90% of the slaughterhouses were small and/or very small plants, similar to others found in previous studies (14, 15, 27, 28). It was hypothesized that slaughterhouses with higher slaughter volumes —at least 80,000 cattle/year (6,700 cattle/month), can invest in aspects related to ensuring product safety, as suggested by other studies (14, 27). Due to their size, very small slaughterhouses have a low income and limited financial resources, so they save on aspects such as performing validation studies of the decontamination process used, acquiring technological resources such as automated intervention systems, and training personnel.

According to national health regulations, the personnel responsible for the operation must understand and conduct the activities under their responsibility (3, 29). Continuous training in aspects associated with carcass decontamination should be reinforced in slaughterhouses since personnel training is essential to produce safe food (15,30).

The use of chemical products such as citric acid, lactic acid, peracetic acid, and a mixture of organic acids in carcass decontamination has also been identified by other researchers for the control of pathogenic microorganisms in meat (31, 32, 33, 34). Although the substances used in the decontamination process vary between slaughterhouses, sprinkling organic acids was also evidenced in a previous study (14).

According to our results, citric acid is the most commonly used product at concentrations between 900 and 1,500 ppm (0.09-0.15%), which is consistent with the product's technical data sheet (i.e., 900-3,000 ppm). However, the concentrations at which the product was being applied were well below, compared to other studies, where 2% citric acid was not enough to significantly reduce pathogens (34, 35). In the current study, it was established that three of the 12 slaughterhouses visited applied lactic acid at concentrations between 1.2 and 2%; however, previous research has recommended the use of lactic acid at concentrations between 2 and 4% to obtain reductions greater than one logarithmic unit (6, 27, 31).

Three of the studied slaughterhouses used peracetic acid at concentrations between 160 and 210 ppm, which is the recommended maximum concentration of 220 ppm (36). However, another study reports that it is not an effective intervention according to what is recognized (35).

It was identified that in most of the slaughterhouses of the study, the method of application of the decontamination product was manual. This type of application is less effective in reducing microbial populations (34). Considering that most of the slaughterhouses in Antioquia are small or very small —many in the latter classification, it is unlikely that the automated application mode was one of the most used since the latter is more suitable for larger slaughterhouses slaughter volumes (15). One explanation is the cost of such equipment and production needs, which makes it more likely to be used by larger slaughterhouses since they have more resources to implement these technologies.

In most of the slaughterhouses visited, it was observed that the operator responsible for the carcass decontamination procedure is not exclusively responsible for conducting this activity, which may increase fatigue. In addition, during the direct observation of the decontamination procedure, the slaughterhouses indicated that they were unaware of the disinfectant volume and application pressure. Other research has reported volumes ranging from 250 to 473 mL per carcass (37), and better results have been reported when using 2 to 3 L per carcass (34) and an application pressure range between 10-123 psi (18, 38). Therefore, and in accordance with what has been pointed out in other studies, in addition to the concentration of the disinfectant, several specific variables of the process must be controlled, such as operator fatigue, pressure or lack of spraying of the product, the volume of the disinfectant applied, time of exposure to the disinfectant, and coverage area of the carcass with the spray, since these factors significantly influence the efficacy of carcass decontamination treatments (31, 34, 41).

According to what was observed, most of the slaughterhouses in the study have implemented an intervention method to control pathogenic microorganisms. In Antioquia, the most used method is washing carcasses with water at room temperature (average 19.9 °C) and sprinkling organic acids. Although it is recognized and accepted that an intervention is effective when it achieves at least a logarithmic reduction (27), and although the effectiveness of this decontamination procedure has been demonstrated, washing with water at room temperature and spraying with organic acids is the least effective alternative since it reduces only 1 to 1.5 logarithmic units (27, 39). Hot water carcass washing was not used in the slaughterhouses study, an intervention that, like chemical disinfection, has increased over time as a pathogen control strategy in the US (15). Other studies have found that the combination of hot water washing (<55 °C) followed by organic acid spraying resulted in additional reductions of 0.2 to 0.5 and of 0.5 to 1.9 log units for *E. coli* O157: H7 and *S. typhimurium*, respectively, which are pathogenic bacteria of interest in meat (6, 35, 15, 40). Furthermore, this strategy could reduce the bacterial load due to cross-contamination and is suggested for small and very small slaughterhouses (26). Therefore, it is considered a viable alternative to improve the conditions of the carcass decontamination procedures, according to the features of the slaughterhouses located in the province of Antioquia.

As discussed above and considering that none of the slaughterhouses visited acknowledge implementing the multi-barrier strategy —including a good preventive intervention such as supplier control, the multi-barrier approach significantly improves results and is more effective than a single intervention is used (14, 41, 42). Combining washing with hot water (<55 °C) followed by spraying with organic acids would be a practical and acceptable option for slaughterhouses in Antioquia.

Most of the slaughterhouses visited carried out a microbiological sampling of the carcasses to verify the effectiveness of the decontamination procedure, an aspect required according to Colombian health regulations (3, 29). However, process control could be improved and monitored through well-designed sampling plans. Therefore, it is agreed to state that although the good manufacturing practices are essential for properly carrying out the slaughter process, pathogen sampling and control plans can help filter contaminated products during the transformation process, stimulate improvements in cleaning and disinfection procedures, and reduce consumer risk and financial costs associated with rejected products by improving product safety (43). In addition, to achieve control of pathogens in carcasses, sanitary standards require the interventions used to destroy and prevent the growth of pathogens to be validated under manufacturing conditions (3, 29). Therefore, it is recommended that the beef carcass decontamination procedure chosen by the slaughterhouses must be validated under the local environments and conditions of each one, as has been recommended in other research works (11,41).

Conclusion

Although it was established that at least one decontamination procedure, such as chemical disinfection, is implemented in the slaughterhouses of study, this option is not supported by scientific or technical foundations. It is likely that, due to limited resources or low income, slaughterhouses are saving on technical factors, technology, and staff training and suitability. These findings support the need for improvements in the slaughterhouses of the province of Antioquia, including the improvement of surveillance programs to effectively reduce pathogens in the meat chain.

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