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Quantification of *Salmonella* Infantis transfer from transport drawer flooring to broiler chickens during holding

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ABSTRACT Transportation is a potential point of cross-contamination before broiler chickens arrive at the processing plant for slaughter. Previous studies have associated the use of uncleaned transport containers with the introduction of pathogenic bacteria onto uncontaminated broilers. The objective of this study was to quantify the transfer of *Salmonella* from transport drawer perforated flooring to broiler chickens during different holding times. For traceability, the flooring of each drawer was inoculated with fecal content slurry containing a marker strain of *Salmonella* Infantis. Three drawers per treatment were used, and each drawer was subjected to one of the following treatments: pressure wash, disinfectant, and pressure wash (A), pressurized steam followed by forced hot air (B), or no cleaning (C). Drawers were classified as top, middle, or bottom based on their relative position with each other. After treatment, broilers were introduced to each drawer and held for 2, 4, or 6 h. At each timepoint, broilers were removed from drawers, euthanized, and carcasses rinsed to obtain *Salmonella* counts. Samples under the limit of direct plating detection were enriched, plated, and later confirmed positive or negative. Differences were observed per treatment, holding time, and drawer relative position ($P < 0.0001$). Broilers placed in transport containers that underwent a cleaning procedure (A or B) had lower levels of *Salmonella* when compared to broilers placed in noncleaned containers (C). However, most of the samples below the limit of detection were positive after enrichment, indicating that both procedures evaluated need improvement for efficient pathogen inactivation. A decrease in *Salmonella* transfer was observed after 6 h in rinsates obtained from broilers placed in noncleaned containers (C). Rinsates obtained from top drawers had less *Salmonella* than the middle or bottom drawers when broilers were placed in transport containers that underwent a cleaning procedure (A and B). The application of pressurized steam and forced hot air was comparable to the use of water washes and disinfectant indicating a potential role in cleaning poultry transport containers.

Key words: *Salmonella*, transport container, horizontal transfer, broiler, holding time

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INTRODUCTION

In 2022, The U.S. Department of Agriculture (**USDA**) Food Safety and Inspection Service (**FSIS**) released a proposed framework to reduce human foodborne *Salmonella* infections associated with poultry meat products. This initiative has been launched as a result of identifying the limitations in the monitoring and verification programs that currently operate in poultry processing facilities (USDA-FSIS, 2022). While the existing monitoring programs show that the established interventions to control bacterial loads have been able to reduce *Salmonella* prevalence over the years, they have not yet led to any reduction in the national *Salmonella* infection rate since the yr 2000, as the Healthy People objectives in reducing *Salmonella* infections transmitted through food were not met in 2010 nor 2020 (USDHHS-ODPHP, 2020; USDA-FSIS, 2022).

The first component of the proposed framework is to require incoming flocks to be tested for *Salmonella* prevalence before being processed. The intent of this first component is to implement a prevention and risk-based

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approach to adequately adapt processes and to take special considerations before the broilers enter the processing plant (USDA-FSIS, 2022). While there are studies assessing the risk of cross-contamination for poultry products during processing and after retail purchase (Nauta et al., 2005; Hue et al., 2010; Jeong et al., 2018), there is not enough information reported to conduct a comprehensive risk assessment for all the steps prior to arrival of the broilers at the processing facilities in the United States (Parsons et al., 2005; McCrea et al., 2006). It is important to note that the risk assessment only provides insight into the degree of factors as potential risks but allows for implementation of customized preventative measures to adequately handle specific scenarios when they are considered out of control (Attrey, 2017).

One potential step for improvement mentioned in the proposed framework for reducing *Salmonella* infections could be the inclusion of measures to address cross-contamination during transportation. Poultry transport containers have been reported as a source of cross-contamination in multiple studies (Slader et al., 2002; Berrang et al., 2003; Rasschaert et al., 2007). Unfortunately, the vast majority of poultry processors in the United States do not have an established procedure to clean and disinfect these transport containers, as reported by Northcutt and Jones in 2004. The uncertain effectiveness and benefits of the current transport container handling methodologies make it challenging for processors to justify the potential economic costs of implementing a cleaning procedure (Northcutt and Jones, 2004).

Previous studies have explored a range of mechanisms to reduce bacterial loads on transport containers, including wet cleaning procedures, the use of different sanitizers and foaming agents, and the application of UV light to transport container flooring (Berrang et al., 2011; Hinojosa et al., 2015, 2018; Moazzami et al., 2021). However, a satisfactory solution for this complex issue is yet to be determined. For poultry processors to willingly adopt a new cleaning practice, the procedure must demonstrate its effectiveness in reducing the target pathogens, while also being fast and cost-effective (Northcutt and Jones, 2004). One possible alternative to save water and time is the application of a thermal intervention as part of the cleaning process for transport containers. Previous studies have evaluated the application of forced hot air or pressurized steam after a water rinse as an option for cleaning fiberglass container flooring. In both studies they observed that the combination of water rinsing followed by a thermal intervention resulted in the greatest decrease in bacterial loads within their treatments, and in some cases reaching undetectable levels (Berrang et al., 2011, 2020).

Nonetheless, most of the studies previously mentioned have only assessed *Campylobacter* as their target microorganism. Few studies have reported the efficacy of such cleaning procedures in reducing *Salmonella* levels (Hinojosa et al., 2018), and unfortunately, they cannot be directly compared with the reductions observed for *Campylobacter*. Both of these pathogens have different morphologies, different growing requirements, and even different survivals rates outside their natural hosts (Jay, 1998; Cebrián et al., 2017; Topalcengiz et al., 2020). Consequently, these different factors result in the creation of a unique risk profile for each one of these pathogens (Slader et al., 2002; De Cesare et al., 2003; McCrea et al., 2006).

For example, De Cesare et al. (2003) evaluated the persistence and survival of *Salmonella* and *Campylobacter* on different food contact surfaces and their findings indicate that *Salmonella* could be up to 25 times more persistent than *Campylobacter* depending on the type of food contact surface. In a separate study conducted by Berrang et al. (2004), they reported undetectable levels of *Campylobacter* on transport container flooring after a drying period of 48 h (placed under a shed at temperature: 24°C−25°C). This finding is in stark contrast to the survival period of *Salmonella* outside their host, which can last up to 308 d in waterfowl feces (stored at room temperature: 22°C) as reported by Topalcengiz et al. (2020).

Therefore, the objective of this study is to quantify the amount of *Salmonella* transferred from transport drawer flooring to broiler chickens while determining the role of wet cleaning procedures, thermal interventions, and no cleaning in reducing *Salmonella* transfer. Additionally, the effect of different contact times and the relative position of the transport drawers on cross-contamination were compared.

MATERIALS AND METHODS

Experimental Design

For this study, perforated plastic transport drawers (1.20 × 1.27 × 0.23 m) and their corresponding metal modules typical for controlled atmosphere stunning systems were used (Baader, UniLoad Live Bird Handling System). The drawers' floors were inoculated with *Salmonella* Infantis and then subjected to one of the following treatments, A) the application of water washes and a commercial disinfectant, B) the application of pressurized steam followed by forced hot air, or C) no-cleaning. Each treatment was placed in a separate metal module containing 3 drawers, in total 9 drawers and 3 metal modules were used in each of 3 repetitions. The drawers were placed in the top 3 slots of their module and classified as top, middle, or bottom in relation to each other. While the plastic drawers were undergoing treatment, the University farm crew caught the birds and placed them into clean plastic chicken coops. After the plastic drawers were treated, 15 broilers (6-wk-old) were randomly selected from their plastic coops and introduced in each drawer and held for 2, 4, or 6 h. At each timepoint, 5 broilers were removed from each drawer, and sampled. For each repetition 135 broilers were sampled and after completing 3 full repetitions of this experiment, a total of 405 observations were obtained. The broilers utilized in this study were sourced from the

Charles C. Miller Jr. Poultry Research & Education Center at Auburn University. These broilers had previously participated in a nutritional trial and were utilized for the present study prior to depopulation. The use of animals in this work was reviewed and approved by the Auburn University Institutional Animal Care and Use Committee (#2021-3884).

Drawer Flooring Inoculation

The total internal area of each drawer was 1.34 m^2, but this area was reduced to 1 m^2 using a wire divider placed lengthwise across the drawer. This application area allowed for accommodation of 15 broilers at 42 d of age and provided an exposure of 100 g of inoculated intestinal contents per m^2. To obtain the intestinal contents, viscera packs were collected from a commercial processing facility the day before the experiment. On the same day, 900 g of intestinal contents from the ceca, colon, and ileum were manually expressed into a sterile beaker and kept refrigerated until the following morning.

To ensure the presence and traceability of *Salmonella*, the intestinal contents were inoculated with a marker strain of *Salmonella* Infantis resistant to 200 ppm of nalidixic acid, which was previously isolated from a water sample collected from a dissolved air flotation (**DAF**) water treatment system from poultry processing plant. To prepare the inoculum, the *Salmonella* marker strain was incubated for 24 h at 37°C in xylose lysine tergitol 4 agar with 200 ppm of nalidixic acid (**XLT4-200NAL**), then 1 colony was transferred onto standard methods agar (**SMA**) and incubated for 24 h at 37°C. The morning of the experiment some colonies were scraped from the SMA surface and suspended in 100 mL phosphate buffered saline (**PBS**) to produce a cell suspension of $\sim 10^8$ CFU per mL when an optical density of 0.15 was achieved at a wavelength of 540 nm.

Then, the 100 mL of *Salmonella* inoculum was added to the 900 g of intestinal contents and mixed thoroughly to obtain a homogenous mixture. The final concentrations of the inoculated intestinal contents were later confirmed by spread plating the serial dilutions on XLT4-200NAL, which were 7.04, 7.77, and 7.78 $\log_{10}$ CFU/g for the first, second, and third repetition, respectively. Before inoculation, the surface of the application area was dry wiped, sprayed with 70% ethanol, and allowed to dry. Once ready, 100 g of inoculated intestinal contents were applied to each drawer only to the floor surface and dispersed evenly with a 7.62 cm disposable paint brush (Project Source, Item: 104125, Model: 150030) across the application area. After inoculation, all the drawers remained at room temperature (23°C) for 1 h before applying any treatment.

Treatment Application

For the first treatment, the drawer floors were water washed and disinfected (A) with a quaternary broad-spectrum disinfectant (United Laboratories, United 262 Hepacide). The first step was 1 water wash applied with a pressure washer using an up-down pattern at approximately 30 cm distance. All water washes were standardized to be applied for 3 min to achieve a visually clean drawer floor surface. The pressure washer was used only with cold water at an operating pressure of 117.21 bar with a 15-degree nozzle and flow rate of 1.7 gpm (AR Blue Clean, Item: 61HL16, Mfr. Model: BC142HS). Then, the disinfectant was applied at a dilution rate of 1:64 until the drawer floor surface was saturated, and a contact time of 10 min was allowed as suggested by the manufacturer. To conclude this treatment, a second water wash was applied as previously described to rinse off the disinfectant.

For the second treatment, pressurized steam followed by forced hot air (B) was applied to clean the drawer floor surfaces. The first step was to apply pressurized steam in an up-down pattern at approximately 6 cm of distance. However, due to noticeable pressure differences between the pressure washer and the steam cleaner, the time of application differed to achieve a visually clean drawer floor. The pressurized steam was applied in sections of approximately 10×10 cm in an up-down pattern and cleaned from left to right. This resulted in a prolonged application time but was standardized to 25 min for each drawer. A commercial steam cleaner (Goodway, Item: 793Z51, Mfr. Model: GVC-1100) was used with a boiler working pressure of 5.52 bar and 171°C. After this step, forced hot air was applied at approximately 30 cm of distance using a heat blower (Master Appliance, Item: 5PYR0, Mfr. Model: AH-301) with an average airflow of 47 cfm at 149°C. The forced hot air was applied in an S-shape pattern across all the drawer entire floor area for 15 min to achieve even drying. Although the time of application applied in this study may not be practical in a commercial setting, it is anticipated that large scale systems purpose-designed for the cleaning of transport containers could achieve the same cleanliness within a shorter timeframe.

Lastly, for the control of this experiment, the drawer floors were not cleaned at all (C). Treatments were performed simultaneously to prevent skewing the results by order of application.

Microbiological Assessment

After treatment, 15 broilers at 42 d of age were immediately introduced to each of the drawers and held for 2, 4, or 6 h. At each time point, 5 birds were removed from each drawer, euthanized, and the entire carcasses (including the feet) were rinsed with 400 mL of buffered peptone water (**BPW**) for 60 s. Samples were kept chilled and transported to the laboratory for the quantification of *Salmonella*. Once in the laboratory, serial dilutions were prepared and spread plated in duplicate on XLT4-200NAL. For samples without *Salmonella* counts (presumptive negatives), 30 mL from the original carcass rinse was placed in a conical tube and incubated for 24 h at 37°C. Then, 0.1 mL was plated on XLT4-

200NAL to confirm the presence or absence of the *Salmonella* Infantis that was spread within fecal content onto the floors of the drawers.

Statistical Analysis

For data analysis, all counts were transformed into $\log_{10}$ CFU/mL, then the analysis was performed using the SAS OnDemand for Academics software. The data obtained for each microbiological test were analyzed per treatment, time, drawer position, repetition, and their interactions using the General Linear Model procedure with means separated by Tukey's honest significant difference with significance at P value ≤ 0.05.

RESULTS AND DISCUSSION

Effect of Treatment on Salmonella Transfer

While the research team made significant efforts to develop the most fitting experimental design and methodology to understand the *Salmonella* transfer during holding, it is imperative to recognize a few constraints inherent in the present study. Broilers were sourced from a university nutritional trial before depopulation and were likely to be negative for naturally occurring *Salmonella*. Prescreening for *Salmonella* that was resistant to 200 ppm of nalidixic acid was conducted on only 5 birds in one of the repetitions. None of these broilers tested positive for *Salmonella* at this antimicrobial concentration. As a result, the experiment proceeded under the assumption that the likelihood of naturally occurring *Salmonella* resistant to 200 ppm of nalidixic acid in the broilers used for this study was minimal. Furthermore, it is unlikely that the fecal material sourced for this work would have contained the elevated levels applied during the inoculation and would therefore only contribute to a low background level. For the results, differences were found among treatments ($P < 0.0001$) and are presented in Table 1. Carcass rinses from broilers that were placed in noncleaned drawers (C: 2.31 $\log_{10}$ CFU/mL) had higher amounts of *Salmonella* than carcass rinses collected from broilers placed in drawers that underwent a cleaning procedure. Both cleaning procedures, A (water wash, disinfectant, and water wash) and B (pressurized steam followed by hot air), were not different from each other (A: 1.39; B: 1.34 $\log_{10}$ CFU/mL). With the exception of one single carcass rinse, all other rinses tested positive for *Salmonella* after enrichment (total prevalence: 404/405). This specific sample was obtained from a broiler placed in a top drawer of treatment A (water wash, disinfected, water wash), and it was collected after 6 h during the second repetition.

Table 1. Prevalence and transfer of *Salmonella* Infantis from transport drawer flooring to broilers and the effect of using different cleaning procedures.

Treatment	$\log_{10}$ CFU/mL	Prevalence[n]
A: Water wash, disinfectant, and water wash	1.39 ± 0.07^{b}	134/135
B: Pressurized steam and forced hot air	1.34 ± 0.06^{b}	135/135
C: No cleaning	2.31 ± 0.05^{a}	135/135

[a,b]Values within a column with different superscripts are significantly different ($P \leq 0.05$). $n = 135$.

The inoculation of the drawer flooring with an artificially high amount of *Salmonella* presented the opportunity to have a deeper understanding of the potential transfer. However, other studies that have documented real-life scenarios reported that initial loads of *Salmonella* were substantially lower than the results presented in this study. For example, Chavez-Velado (2022) evaluated the initial load of *Salmonella* at live receiving in 3 different processing plants. In that study, the *Salmonella* loads observed before the broilers enter each processing plant were 2.39, 2.83, 2.78 $\log_{10}$ CFU/30 mL (of a 400 mL carcass rinsate) for the first, second, and third processing plant, respectively.

In a different study, De Villena et al. (2022) reported similar results to Chavez-Velado (2022). This study assessed the levels of *Salmonella* for a single processing plant during live receiving, reporting 2.63 $\log_{10}$ CFU/30 mL. When adjusting the results of the present study to a volume of 400 mL (volume of BPW used per each carcass rinse), the *Salmonella* loads obtained were notably higher even for the broilers placed in drawers that underwent a cleaning procedure (A: 3.42; B: 3.44; C: 4.90 $\log_{10}$ CFU/30 mL). Nonetheless, only a broad comparison could be made since neither Chavez-Velado (2022) nor De Villena et al. (2022) disclosed information on whether the sampled broilers were placed in cleaned or noncleaned transport containers.

Borges et al. (2019) conducted a study to quantify *Salmonella* across the slaughtering process. Despite subjecting the transport containers to a cleaning and disinfecting procedure, no reductions in *Salmonella* were observed on transport flooring (2.77 $\log_{10}$ CFU/mL before cleaning and 2.96 $\log_{10}$ CFU/mL after cleaning). This lack of effectiveness in cleaning and disinfecting the transport containers allowed for a comparison between the results of carcass rinses obtained before scalding by Borges et al. (2019) and those obtained from broilers placed in noncleaned drawers in the current study. In their study, Borges et al. (2019) reported the loads of *Salmonella* from broiler carcasses before scalding were 3.04 $\log_{10}$ CFU/mL, which aligns to the loads observed in this study for broilers placed in noncleaned drawers (C: 2.31 $\log_{10}$ CFU/mL). This comparison reinforces that broilers placed in containers that were either noncleaned or inadequately cleaned could present comparable recovery level.

It is worth emphasizing that the *Salmonella* loads observed during holding prior to slaughter could remain at similar levels even after scalding and picking. As an example, Chavez-Velado (2022) documented that 1 of the 3 processing plants included in their study did not demonstrate a reduction in *Salmonella* loads when evaluating the levels at the rehang (1.85 $\log_{10}$ CFU/400 mL) compared to the levels observed during live receiving (2.39 $\log_{10}$ CFU/400 mL). Also, in the study conducted

by Borges et al. (2019) a similar trend was reported. In that study, there was a *Salmonella* reduction observed after plucking (1.16 $\log_{10}$ CFU/mL) but the reduction was not observed when resampled after the initial carcass wash (3.64 $\log_{10}$ CFU/mL). However, it is important to note that the results can vary depending on specific circumstances. De Villena et al. (2022) and Chavez-Velado (2022) also documented cases in which *Salmonella* loads considerably decreased before reaching rehang.

In the case of *Salmonella* prevalence, the present study is comparable to the results presented by other studies (Chavez-Velado, 2022; De Villena et al., 2022). In the present study, the overall prevalence of *Salmonella* was 99.8%, while De Villena et al. (2022) reported a prevalence of 94% for a single processing plant and Chavez-Velado (2022) documented *Salmonella* prevalence ranging from 87 to 98% in 3 separate processing plants. As mentioned earlier, the loads observed in both of those studies (Chavez-Velado, 2022; De Villena et al., 2022) were considerably lower compared to the loads observed in the current study. This serves as a clear example that relying solely on prevalence does not provide comprehensive insight into the *Salmonella* status of an incoming flock. The findings of the current study indicate that the process of cleaning transport containers reduces the transfer potential of *Salmonella* during holding.

The results of the carcass rinses obtained from treatment A (water wash, disinfectant, and water wash) and B (pressurized steam followed by hot air) indicate that the cleaning procedures evaluated reduce the transfer of *Salmonella* but did not achieve a complete inactivation or removal from the transport drawers, which concurs with previous studies that have reported remaining levels of bacteria after evaluating cleaning and disinfecting procedures for transport container flooring (Ramesh et al., 2002; Berrang and Northcutt, 2005; Hinojosa et al., 2015, 2018). Although reductions in transfer were not as distinctively perceptible in a logarithmic scale, when analyzing the transfer on an arithmetic scale (A: 122; B: 65; C: 394 CFU/mL), it showed that the incoming *Salmonella* loads could decrease by 69 to 83% when broilers are held in drawers that have undergone a cleaning procedure. Nauta et al. (2005) created a model for a quantitative microbiological risk assessment which favored the addition of arithmetic means to provide a deeper understanding of cross-contamination rates and incoming loads to the processing plant.

Effect of Holding Time on Salmonella *Transfer*

As differences among treatments have been previously reported above, a comparison within each treatment was performed to observe the effect of holding time on *Salmonella* transfer, with results presented in Table 2. No effect of holding time is observed for the carcass rinses obtained from treatment A (water wash, disinfectant, and water wash) and B (pressurized steam followed by hot air), as 2, 4, or 6 h did not differ from each other within each treatment. For treatment C (no cleaning), a higher amount of *Salmonella* was observed from carcass rinses collected at 2 h (2.58 $\log_{10}$ CFU/mL) than those collected at 6 h (2.05 $\log_{10}$ CFU/mL). The carcass rinses obtained after 4 h (2.32 $\log_{10}$ CFU/mL) were comparable to those collected at either 2 or 6 h.

While no previous studies were found to be directly comparable to the present study, other research that has used food matrices and food contact surfaces have reported similar trends. For example, Moore et al. (2007) evaluated the transfer of *Salmonella* Typhimurium from different domestic food contact surfaces to cucumber slices with a 10 s contact time. The results reported by Moore et al. (2007) showed that transfer of *Salmonella* Typhimurium decreased over a period of 6 h regardless of the type of food contact surface inoculated (stainless steel, Formica, polypropylene, and wood). Furthermore, these studies reported a higher transfer from all contact surfaces when bacteria were suspended in high protein media, although variations were observed depending on the type of surface inoculated. For the specific case of polypropylene surfaces inoculated with *Salmonella* Typhimurium suspended in a high protein media showed a rapid decreased of transfer (with 10 s contact time) over a period of 5 h, reaching undetectable levels.

When the previous scenario is compared to the samples obtained from broilers placed in noncleaned drawers, a slight resemblance can be observed (Moore et al., 2007). However, the transfer of *Salmonella* from the plastic drawers to the broilers in the present study did not decrease to undetectable levels, this outcome could potentially be attributed to the favorable type of matrix used for inoculation (fecal contents) as previous studies have shown the lengthy resilience of *Salmonella* in animal feces (Topalcengiz et al., 2020).

Additionally, the trend of *Salmonella* transfer rate reducing over time has been reported and supported by other studies that have evaluated different combinations of contaminated surfaces and food matrices. However, these matrices evaluated have been inanimate objects that were placed onto inoculated surfaces for a delimited contact time at specific times after inoculation (Kusumaningrum et al., 2003; Moore et al., 2003; Dawson et al., 2007). This differs from the present study where a live animal was placed and held for hours within a transport container, and a certain degree of movement is expected within the container.

Table 2. Transfer of *Salmonella* Infantis from transport drawer flooring to broilers and the effect of different cleaning procedures measured at different timepoints during holding.

	$\log_{10}$ CFU/mL		
Treatment	2 h	4 h	6 h
A: Water wash, disinfectant, water wash	1.55 ± 0.13	1.39 ± 0.14	1.23 ± 0.11
B: Pressurized steam and forced hot air	1.57 ± 0.11	1.19 ± 0.12	1.25 ± 0.10
C: No cleaning	2.58 ± 0.06[a]	2.32 ± 0.08[ab]	2.05 ± 0.08[b]

[a,b]Values within a row with different superscripts are significantly different ($P \leq 0.05$). $n = 45$.

Table 3. Transfer of *Salmonella* Infantis from transport drawer flooring to broilers and the effect of different cleaning procedures by drawer relative position.

	$\log_{10}$ CFU/mL		
Treatment	Top	Middle	Bottom
A: Water washes and disinfectant	0.92 ± 0.12^{b}	1.60 ± 0.14^{a}	1.65 ± 0.10^{a}
B: Pressurized steam and forced hot air	0.68 ± 0.10^{b}	1.57 ± 0.09^{a}	1.76 ± 0.07^{a}
C: No cleaning	2.18 ± 0.09	2.31 ± 0.08	2.45 ± 0.08

[a,b]Values within a row with different superscripts are significantly different ($P \leq 0.05$). $n = 45$.

Effect of Drawer Relative Position on Salmonella *Transfer*

As differences among treatments have been previously established above, a comparison within each treatment was performed to observe the effect the drawers' relative position on *Salmonella* transfer, with results presented in Table 3. For treatment C (no cleaning), no differences were observed based on the drawers' relative position. Both cleaning procedures, A (water wash, disinfectant, and water wash) and B (pressurized steam followed by hot air) shared a similar trend where the carcass rinses collected from the broilers placed in the top drawers (A: 0.92; B: 0.68 $\log_{10}$ CFU/mL) had lower counts than those collected from the broilers placed underneath them (A: 1.60 and 1.65 $\log_{10}$ CFU/mL for middle and bottom drawer, respectively; B: 1.57 and 1.76 $\log_{10}$ CFU/mL for middle and bottom drawer, respectively).

While it is possible to attribute the observed effect to the perforated floor design of the transport drawer, existing studies directly comparable to the results presented in this study were not found. The plastic drawers used for this experiment had perforated floors to enhance ventilation within the module, but fecal material from the top drawers passed through acting as a vehicle for cross-contamination within the module. If a transport drawer becomes contaminated with *Salmonella*, it poses a risk not only to the birds placed in that specific drawer but also to all the birds placed underneath. Alm et al. (2014) documented a similar trend but evaluating the collection of droppings from a furnished 8-hen cage set up in 3 tiers. Alm et al. (2014) consistently collected more droppings from the bottom tiers of the cages when compared to top tiers of the cages. However, in their study a manure belt was placed under each level, and they did not report manure moving from the top to the bottom, for which, the cause for this effect was left unknown for their experiment (Alm et al., 2014).

CONCLUSIONS

The application of pressurized steam followed by forced hot air was comparable to the application of water washes and disinfectant for cleaning plastic transport drawers. Both cleaning procedures effectively decreased the transfer of the evaluated *Salmonella* Infantis strain to the broilers when compared to noncleaned drawers, however, neither achieved complete pathogen inactivation or removal from flooring of the drawers. Moreover, it was observed that the transfer of the evaluated *Salmonella* Infantis strain from the plastic drawer flooring to the broilers could be influenced by the duration of holding and the relative position of the drawer within the module, which could result in points of interest to lessen cross-contamination during transport. The results of this study indicate that the application of pressurized steam and forced hot air have a potential role in cleaning poultry transport drawers and adaptations could be considered for a larger scale.

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DISCLOSURES

All authors declare no conflicts of interest.

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