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Effect of light-touch intervention and associated factors to microbial contamination at small-scale pig slaughterhouses and traditional pork shops in Vietnam

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ABSTRACT

Traditional pork value chains dominate the production and distribution of pork in Vietnam; however, the high level of microbiological contamination in pork may increase the risk of food-borne disease for consumers. There is limited evidence about how to feasibly and scalably reduce microbial contamination in pork sold in traditional markets. This study aimed to assess the effectiveness of light-touch interventions for changing worker behaviour in small-scale slaughterhouses and vendors at traditional pork shops, as well as to identify risk factors for pork contamination. The intervention packages consisted of providing hygiene tools and delivering a food safety training which had been designed in a participatory way and covered 10 small-scale slaughterhouses and 29 pork shops. Pig carcasses, retailed pork, contact surfaces, and hands were sampled to measure the total bacterial count (TBC) and *Salmonella* contamination before, three and six weeks after the intervention, and trainee practices were observed at the same time. Linear and generalized linear mixed effects models were constructed to identify risk factors for TBC and *Salmonella* contamination at the slaughterhouses and pork shops. The interventions at slaughterhouses and pork shops both showed a slight reduction of TBC contamination in pig carcasses and *Salmonella* prevalence in retailed pork, while the TBC in retailed pork decreased only marginally. For slaughterhouses, the regression model indicated that smoking or eating during slaughtering (indicating poor hygienic practices) was associated with TBC increasing, while cleaning floors and wearing boots reduced TBC contamination. For pork shops, using rough materials (cardboard or wood) to display pork was the only factor increasing TBC contamination in pork, whereas cleaning knives was associated with lower TBC. Besides, the presence of supporters and wearing aprons reduced the probability of *Salmonella* contamination in pork. The findings highlight the effectiveness of light-touch interventions in reducing microbial contamination in pig carcasses at small-scale slaughterhouses and pork at traditional shops over the study period.

1. Introduction

Small-scale pork producers play an important role in the pork sector in Vietnam. In 2016, the number of small-scale household farms, having less than 5 pigs/farm, accounted for 67.5 % of households raising pigs (General Statistics Office, 2019). More than half of those pigs are

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slaughtered by small-scale (less than 6 pigs/day) slaughterhouses, where pig carcasses are mainly processed on the floor during the slaughtering operation (Thi Duong Nga et al., 2017; Yokozawa et al., 2016). Pork products are then sold to consumers via the traditional, public, wet markets, the dominant distribution channel for food products, which have limited facilities for hygiene and food preservation (Dang and Ngo, 2018; Ngo et al., 2021; Tisdell et al., 2010). After the African swine fever outbreak in 2019 in Vietnam, the contribution of the traditional pork value chain was expected to gradually decrease and be replaced by the larger commercial actors as a result of the government's long-term strategy (Nguyen-Thi et al., 2021). However, the annual incidence of salmonellosis due to consuming pork in Vietnam was estimated to be 17.7 % which alarming the high burden of pork-borne disease (Dang-Xuan et al., 2017). While waiting for the slow transition towards formal markets, it is necessary to improve food safety conditions for the traditional pork producers to promptly reduce the burden of pork-borne disease.

Pork products are considered a source of several foodborne pathogens, such as *Salmonella, Streptococcus*, *Trichinella,* and *Taenia solium* (Ho et al., 2011; Le et al., 2022; van De et al., 2015; Vu Thi et al., 2014; Willingham et al., 2010). Recent studies reported a high prevalence of microbial contamination across traditional pork value chains, from slaughterhouse (25 % to 60 % of pork samples were positive with *Salmonella*) (Dang-Xuan et al., 2019; Le Bas et al., 2006; Thi Ngoc Pham et al., 2012; Yokozawa et al., 2016) to different types of retail outlets (58 % to 73 % pork samples were positive with *Salmonella* and 90–94 % samples did not meet the Vietnamese standard for total bacterial count (TBC) in meat (lower than 5.7 $\log_{10}$ colony forming units (CFU) per gram, which is an important hygiene indicator) (Dang-Xuan et al., 2019; Ngo et al., 2021; Nguyen et al., 2016; Nguyen-Viet et al., 2019; Nhung et al., 2018; Phan et al., 2005). While the prevalence of parasites in pork could only be reduced by intervention at farm level, the improvement of hygiene procedures at slaughterhouses and pork shops might reduce the bacterial contamination in pork (Nguyen-Viet et al., 2017; The World Bank, 2017). However, the estimated cost of controlling microbial contamination, *Salmonella* for example, via improving infrastructure was found to be unaffordable for small-scale pork value chains and inappropriate to apply in the Vietnamese context due to the weak capacity of food safety regulation enforcement (Dang-Xuan et al., 2019; Nguyen-Viet et al., 2017). We hypothesized that in traditional value chains, low-cost and light touch techniques and food safety practices would be most effective improve the safety of pork (Hennessey et al., 2020; The World Bank, 2017). The light-touch intervention approach focuses on changing behaviour via training, feasible infrastructure upgrades, incentives and an enabling environment (Grace et al., 2020). In addition, interventions should be applied along the pork value chain in order to avoid contamination at any production stage (Choi et al., 2013). In our literature review, there are several potential interventions to improve pork safety at slaughter such as spraying acid lactic on the carcass or applying steam vacuum or steam ultrasound (Bapista et al., 2011; Lawson et al., 2009; Van Ba et al., 2019). However, there was no report that evaluated the effectiveness of feasible intervention packages to improve the safety of pork across small-scale value chains in Vietnam context, although several general hygiene practice recommendations and guidelines have been disseminated to pork value chains actors by food safety authorities and programs. Therefore, this study aimed to (i) evaluate the effectiveness of a light-touch intervention in reducing microbial contamination in small-scale pig slaughterhouses and traditional pork shops, and (ii) identify the relationship between contamination of pork products and capacity, facilities, and food safety practices of pork suppliers in order to further refine interventions.

2. Methodology

2.1. Study location and recruitment of participants

The location of this study included four northern provinces in Vietnam, namely Hung Yen, Nghe An, Hoa Binh, and Thai Nguyen. The study sites were selected following the guidelines and criteria developed by the SafePORK project (ACIAR, 2016). Each province represented areas with different types of pork value chains. Pork value chains in Hung Yen and Nghe An were characterized as rural area, Thai Nguyen as peri-urban and urban areas, while Hoa Binh represented a rural area with indigenous pig production by ethnic minorities.

To select slaughterhouses, local authorities in each province shared the list of establishments that used floor-based slaughtering, with the capacity varying between 1 and 20 pigs/day. The research team then explored all suggested slaughterhouses to assess the existing facilities and food safety condition and discussed with the owners to probe their motivation and willingness to participate in the intervention. Other conditions for selecting slaughterhouses were based on their possibility of implementing the intervention package, for instance, the existence of separate places for exsanguinating pigs or splitting the carcass and removing stagnant water or other animals from the slaughter area. Ten small-scale slaughterhouses were selected.

To select markets and pork shops, the research team investigated the traditional markets in the surrounding areas where the selected slaughterhouses provided pork for some retailers. In addition, eligible markets should be under the control of communal authorities and have a market management board to support and manage the market operations. The selected markets were also required to have specific areas for selling animal-source food, with tables to display pork, and to be able to adopt the intervention design. The other basic market facilities required were availability of water supply and a drainage system. Three markets were selected, one in Hung Yen and two in Thai Nguyen. At the market in Hung Yen, 14 pork shops were all invited to participate in the intervention, while in Thai Nguyen, seven and eight out of 15 pork shops in each of two selected markets were randomly selected. A total of 29 pork shops that sold from 20 to 200 kg pork per day were enrolled in the intervention.

Upon voluntary agreement to join the intervention of the slaughterhouse owners and pork retailers, baseline surveys (practice observation and sampling) were conducted.

2.2. Intervention design

The intervention at slaughterhouses comprised two parts: upgrading slaughtering facilities and delivering food safety training to the slaughterhouse workers and owners. Specifically, stainless-steel grid was installed elevate the carcass from direct contact with the ground. The size of the grid was co-designed with the owner based on actual measurements at slaughterhouse according to the facilities, capacity and common weight of slaughtered pigs. In addition, the water system was adjusted by installing new hoses and taps to encourage the workers to clean tools, hands and the floor while slaughtering. Later, on the same day or the day after the grid installment, the research team introduced the workers to grid-based slaughtering and instructed them on good food safety practices in pig slaughtering. The adjustments and training session were designed specifically for each slaughterhouse after consultation with the owner and workers. The training materials were developed based on the adjustments and followed the local regulations on food safety at slaughtering establishments (Ministry of Agriculture and Rural Development, 2018; National Agro-Forestry-Fisheries Quality Assurance, 2014).

Similarly, for the pork shops, the intervention included equipping shops with new tools and providing food safety training. The new tools consisted of apron, cutting board, cloths, disinfection liquid, sprayer and hand sanitation gel, as well as posters reminding them to maintain hygiene practice during sale. One or two days after provision of tools, a food safety training session was delivered to the retailers to introduce them to the hygiene tools and food safety practices at retail level. The training materials were developed followed the local regulations on food safety at meat trading establishment (Ministry of Agriculture and Rural Development, 2012; Ministry of Industry and Trade, 2017; National Agro-Forestry-Fisheries Quality Assurance, 2014).

2.3. Sampling design

For both slaughterhouse and pork shop, there were three rounds of microbial testing across the implementation of the intervention packages. The first sampling round, constituting the baseline, was conducted one week before installing or equipping any items. The second sampling round was carried out during the third week after the end of the training session. The third sampling round was the end-line was during the sixth week.

At the slaughterhouses, all carcasses on the visit day were sampled during each round. For each carcass, a total of 400 cm^2 from four positions (100 cm^2 each) of inner of half carcass surface (lower part of neck, mid-back, abdomen, and hind limb) was swabbed at the final washing step, right before transporting to the market following the ISO 17604: 2003 procedure (ISO, 2003). Slaughter floors and workers' hands swab samples were also collected. For each visit, 100 cm^2 area of the slaughter floor (where the carcass splitting was performed) and one to three workers were selected for swabbing hands.

At the pork shop, the research team took one sample of retailed pork (300 to 400 g per sample) as well as swabbed retailers' hands and 25 cm^2 surface of cutting board for each visit. The detailed steps to select and take samples followed the procedure described by Dang-Xuan et al. (2018, 2019).

All the samples were analyzed for the total bacterial count (TBC) using the ISO 4833-2: 2013 procedure (ISO, 2013). All retail pork samples were also analyzed for the presence or absence of *Salmonella* following the ISO-6570: 2002 procedure (ISO, 2002), and one of every two pork samples was randomly selected to analyze *Salmonella* concentration following the 3-tube most probable number (MPN) method. These procedures are described in detail in previous publications by Dang-Xuan et al. (2018) and Ngo et al. (2021). The total number of samples analyzed are presented in Table 1 below.

Table 1
The total number of microbial samples at slaughterhouses and pork shops analyzed for either total bacteria count (TBC) or *Salmonella* spp.

Type of sample and test	Slaughterhouse			Pork shop		
	Round 1[a]	Round 2	Round 3	Round 1	Round 2	Round 3
Carcass swab (TBC)	20[b]	20	20	–	–	–
Pork						
TBC	–	–	–	29	29	29
Salmonella qualitative	–	–	–	29	29	29
Salmonella quantitative	–	–	–	14	14	14
Surface (TBC)						
Floor swab	10	10	10	–	–	–
Cutting board swab	–	–	–	29	29	29
Worker's/ seller's hand swab (TBC)	14	14	14	29	29	29

[a] Round 1: Before intervention, round 2: 2–3 weeks after training, round 3: 6 weeks after training.
[b] 20 samples were taken in the 10 slaughterhouses and on average two samples per slaughterhouse.

2.4. Data collection

Observation checklists were developed by the research team to record the compliance of participants with the inculcated practices and the food safety condition of the slaughterhouse or pork shop during operations on the sampling day. The checklist for slaughterhouses was based on the Vietnamese regulation for assessment of food safety regulations of slaughterhouse (Circular No. 38/2018/TT-BNNPTNT, 2018), while the checklist for pork shops was based on the Vietnamese standard for food business markets (Ministry of Industry and Trade, 2017b). The checklists were developed in Vietnamese language and pre-tested in Hung Yen province.

2.5. Data analysis

Microbial and observation data were entered in Microsoft Excel and analyzed using R (R Core Team, 2022). The TBC was transformed into log_{10} colony forming units (CFU)/g (for pork samples), log_{10} CFU/cm^2 (for carcass, cutting board and floor samples) or log_{10} CFU/hand (for hand samples) before analyses. To evaluate the difference in microbial results at different stages of the intervention, McNemar's test was applied to assess the change in *Salmonella* prevalence, while the Wilcoxon signed rank test was implemented for the TBC. The significance level of 5 % was considered for both tests.

Before conducting regression analysis, we used two causal diagrams created in Dagitty.net (http://www.dagitty.net/dags.html) to determine independent variables and potential confounders of the dependent variables, which were the TBC of pig carcass and microbial contamination of pork sample (Fig. 1 below). The TBC of hands, floors and cutting boards were indicated as mediator variables and excluded from all multivariable models while the capacity, sale volume, and facilities were considered as confounders and put in all models to control for this. Then, univariable analyses were implemented to select independent variables which had *p*-value lower than 0.2. Later, backward stepwise regressions were conducted with all independent variables selected from the univariate analyses. Only variables with *p*-value equal or less than 0.05 remained in the final models. For slaughterhouses, the dependent variable was the log_{10} CFU of TBC in pig carcass, and slaughterhouse, round were set as random effects using the linear mixed-effects models (LMM) in lme4 package (Bates et al., 2015). The same model was applied for pork shops with the log_{10} CFU of TBC in retailed pork as the dependent variable and market and round were set as random effects. In addition, the generalized linear mixed-effects models (GLMM) were used to analyze the effect of sale volume, facilities and practices at pork shops on the presence of *Salmonella* in retailed pork, and market was again set as a random effect.

2.6. Ethical considerations

This study was reviewed and approved by the Institute Review Board at the Hanoi University of Public Health (No 110/2018/YTCC-HD3). Verbal consent was also obtained from each participant before implementing the intervention, sampling and observation.

3. Results

3.1. Demographic characteristics

All the participating slaughterhouses had two to three permanent workers who slaughtered up to three pigs per day, except one slaughterhouse which slaughtered four to six pigs per day (Supplementary 1). Nine out of ten slaughterhouses purchased the pigs from local farms within the same district and operated with the involvement of pork retailers, who were also their customers. Only five slaughterhouses equipped the workers with boots while six out of ten had facilities for hand washing. Six out of ten applied stunning in the slaughtering

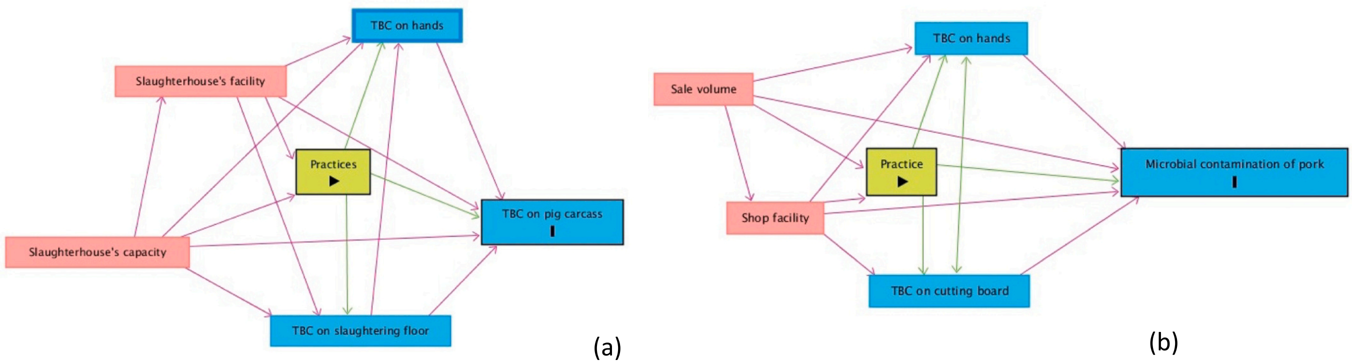

Fig. 1. Causal diagrams for slaughterhouse (a) and pork shop (b) show exposure variables of interest (green rectangles with black triangle), intervening variables (light blue rectangles) and potential confounders (pink rectangles) related to the outcome variables (dark blue rectangles with a vertical bar), adapted from source http://www.dagitty.net/dags.html). Slaughterhouse facility includes variables related to infrastructure, workers and water system; shop facility includes variables related to tools and equipment (such as tray to separate intestine with raw or cooked pork or insect control system)

procedure. On average, the slaughterhouses employed around twice as many men as women.

For the pork shops, almost all the retailers (96.6 %) were female with a mean age of 50 years, and half of them had middle school education. More than one-third were helped by one or two people from their family in pork selling. An average retailer needed approximately 12 min to transport the pork 4 km from the slaughterhouses to the market by motorbike or bicycle without cooling equipment, and had an average sale volume of 43 kg pork per day. Details are presented in Supplementary 1.

3.2. Intervention result

3.2.1. Microbial results

Table 2 presents the microbial contamination of different samples at different stages of intervention at slaughterhouse and pork shop. For the slaughterhouses, the microbial results showed significant improvement in TBC after implementing intervention packages. In detail, the $\log_{10}$ TBC of the carcass showed a tendency to reduce after intervention, although this reduction was not significantly different. Besides, the floor samples showed a remarkable decline in TBC from 6.01 (round 1) to 4.41 (round 2, $p = 0.002$) and 4.61 (round 3, $p = 0.03$). However, TBC on workers' hands remained unchanged across the three sampling rounds. For the pork shops, no samples showed any significant decrease in TBC, although the pork and cutting board samples had a slight reduction. On the other hand, *Salmonella* contamination reduced considerably, with the prevalence halved from 52 % in first round to 28 % (round 2) and 24 % (round 3) in the later rounds although this reduction was not statistically significant at 5 % level. Similarly, the average concentration of *Salmonella* in the positive samples was 1.53 MPN/g (SD: 1.53) in the first round (average of six positive samples), which decreased to 1.18 MPN/g (SD: 1.16) in the second round (average of three positive samples) and 1.19 MPN/g (SD: 1) in the third round (average of three positive samples) but the sample sizes were too small for any statistical tests.

Table 2
Microbial results as average log colony forming units (CFU) (minimum-maximum) of total bacterial count (TBC), as well as prevalence of at slaughterhouse and pork shop before (Round 1) and after the intervention (Round 2 and 3).

Microbial result	Round 1	Round 2	Round 3
Slaughterhouse (TBC)			
Pig carcass ($\log_{10}$ CFU/cm^2)	4.46 (3.48–6.64)	4.23$^{*, a}$ (2.75–5.6)	4.37 (3.05–5.74)
Floor ($\log_{10}$ CFU/cm^2)	6.01 (5.38–7.06)	4.41$^{***, a}$ (3.31–6.12)	4.61$^{**, a}$ (2.87–7.12)
Worker hand ($\log_{10}$ CFU/hand)	7.09 (5.33–8.54)	7.07 (4.57–8.65)	7.04 (5.83–8.85)
Pork shop (TBC or *Salmonella* contamination)			
Pork ($\log_{10}$ CFU/g)	5.47 (3.26–7.18)	5.34 (4.17–6.81)	5.36 (4.35–6.34)
Cutting board ($\log_{10}$ CFU/cm^2)	7.69 (5.87–10.31)	7.55 (5.75–8.94)	7.40 (6.20–9.38)
Seller's hand ($\log_{10}$ CFU/hand)	6.47 (3.41–8.33)	6.36 (4.77–8.38)	6.97 (4.73–8.33)
Salmonella prevalence on pork	52 %	28 %$^{*, b}$	24 %$^{*, b}$
Salmonella concentration (MPN/g) $^{\#}$	1.53	1.18	1.19

*, **, *** significant at 10 %, 5 % and 1 % level, respectively, compared to round 1.
[a,b]: Wilcoxon's test and McNemar's test.
#: Calculated mean of *Salmonella* positive samples.
Parentheses present the minimum and maximum TBC values.

3.2.2. Food safety practices

Table 3 presents the food safety practices of slaughterhouse workers across different rounds of observation. At slaughterhouses, the workers improved considerably in the frequency of washing knives with water after bleeding and eviscerating (from 25 % and 45 %, to 60 % and 90 %, respectively), washing the slaughterhouse floor after eviscerating and slaughtering (from 45 % and 35 %, to 90 % and 80 %, respectively) and handling intestines separately (from 60 % to 80 %) after receiving the intervention packages. These improvements were also maintained in the third round. In contrast, the frequency of handwashing (70 %), keeping knives off the floors (80 %) and wearing boots (80 %) seemed to be unchanged, while the frequency of smoking or eating in the slaughterhouse increased from 20 % to 40 % across three rounds of observation.

At pork shops, the retailers showed remarkable increase in the frequency of good practices, including covering pork when transporting (from 34 % to 62 %), using different cloths for wiping hands, pork or equipment (from 3.5 % to 55 %), cleaning hands, cutting boards or knives while selling (from 0 % to 76 %, 55 % and 59 %, respectively) and wearing aprons while selling (from 62 % to 90 %). Other practices (cleaning tables after selling and not eating or smoking while selling) witnessed unchanged frequency and the retailers maintained a high regularity (more than 70 %) during each round. The frequency of cleaning tables before selling increased in the second round (from 45 % to 79 %) but it tended to drop in the last round of observation (Table 4).

Table 3
Change in food safety practices of slaughterhouse workers before and after the intervention.

Practice	Frequency		
	Round 1	Round 2	Round 3
There were pests, insects or rodents in the slaughter area			
Yes	12 (60 %)	9 (45 %)	4[a] (20 %)
No	8 (40 %)	11 (55 %)	16 (80 %)
Workers cleaned knives with water after eviscerating pigs			
Yes	9 (45 %)	13 (65 %)	18[a] (90 %)
No	10 (50 %)	7 (35 %)	2 (10 %)
NA	1 (5 %)	–	–
Workers cleaned the floor with water after carcass splitting			
Yes	9 (45 %)	13 (65 %)	18[a] (90 %)
No	10 (50 %)	7 (35 %)	2 (20 %)
NA	1 (5 %)	–	–
Workers cleaned the floor with water after finished slaughtering			
Yes	7 (35 %)	13 (65 %)	16[a] (80 %)
No	12 (60 %)	7 (35 %)	4 (20 %)
NA	1 (5 %)	–	–

NA: Not possible to observe.
[a] McNemar's test is significant at 5 % level compared to round 1.

Table 4
Change in food safety practices of pork sellers before and after the intervention.

Practice	Frequency		
	Round 1	Round 2	Round 3
Sellers wore aprons			
Yes	18 (62.07 %)	26** (89.66 %)	26** (89.66 %)
No	11 (37.93 %)	3 (10.34 %)	3 (10.34 %)
Seller wiped hands, pork or tools with different cloths			
Yes	1 (3.45 %)	12** (41.40 %)	16** (55.17 %)
No	28 (96.55 %)	17 (58.60 %)	13 (44.83 %)
Sellers cleaned table surfaces with water before selling			
Yes	13 (44.83 %)	23** (79.31 %)	16 (55.17 %)
No	15 (51.72 %)	4 (13.79 %)	13 (44.83 %)
NA	1 (3.45 %)	2 (7.90 %)	–

**,*: McNemar's test is significant at 1 % and 5 % level, respectively, compared to round 1.
NA: Not possible to observe.

3.3. Factors associated with microbial contamination

At slaughterhouse, unhygienic practice such as smoking or eating while slaughtering associated with increased $\log_{10}$ CFU of TBC in pig carcass (95 % confidence interval [CI]: 0.24 to 1.09; $p = 0.005$). In contrast, wearing boots (CI: −1.33 to −0.27, $p = 0.004$) and cleaning floors after slaughtering (CI: −0.86 to −0.07, $p = 0.02$) were significantly associated with lower TBC of pig carcasses.

At pork shops, wearing aprons (odds ratio [OR] = 0.17, $p = 0.02$) and the existence of helpers at the market (OR = 0.14, $p = 0.02$) were associated with reduced TBC and *Salmonella* positivity risk. In addition, cleaning knives was also associated with lower TBC in retailed pork (CI: −0.70 to −0.04, $p = 0.04$). On the other hand, the use of rough material (cardboard or wood) to cover the table was associated with higher TBC in retailed pork (CI: 0.001 to 0.61, $p = 0.02$). The detailed results are presented in Table 5.

4. Discussion

Our study examined the effectiveness of light-touch interventions and investigated risk factors related to microbial contamination in pig carcasses and pork at small-scale slaughterhouses and traditional pork shops in Vietnam. Since the traditional pork value chain dominates pork production in Vietnam, the findings from this study can contribute significantly towards improving the safety of pork in Vietnam.

Overall, the intervention packages considerably reduced the microbial contamination across the traditional pork value chain. At slaughterhouses, the TBC of floor surfaces reduced by approximately 1.5 log after the intervention. The increase in floor cleaning frequency during slaughtering and the installment of the stainless-steel grid contributed to this improvement. In addition, the microbial contamination of pig carcasses reduced slightly from 4.46 to 4.37 $\log_{10}$ CFU/cm^2 after implementing the intervention packages while the workers' hand did not change significantly.

At pork shops, despite the improvement in food safety practices of sellers, the TBC in pork, on cutting boards and on sellers' hands were consistent across stages. However, the level of bacterial contamination in pork (5.34 to 5.47 $\log_{10}$ CFU/g) was still lower than the Vietnamese standard for microbiological contamination in meat (5.70 $\log_{10}$ CFU/g) (MOH, 2012) and that reported from previous studies in Vietnam (Ngo et al., 2021; Nguyen-Viet et al., 2019) and India (Bradeeba and Sivakumaar, 2013), while the TBC on sellers' hands (6.36–6.97 $\log_{10}$ CFU/hand, assuming a hand's swab equals to 100 cm2) was comparable to the findings in the study of Adikwu et al. (2019) (8.02 to 8.26 $\log_{10}$ CFU/cm^2). However, these figures were 0.5 log lower than the TBC on slaughterhouse workers' hands. An interpretation might be the difference in the intervention design since the packages at pork shop consisted of more items to encourage hand cleaning compared to the package at slaughterhouse. Thus, the bacterial contamination of retailed pork was acceptable and hardly improved with limited changes in practices. On the other hand, the prevalence of *Salmonella* on pork reduced considerably after the sellers adopted the intervention packages; the *Salmonella*

Table 5
Multivariable analysis results of risk factors associated with total bacterial count in carcasses at slaughterhouses and pork at traditional shops (linear mixed-effects model) and presence of *Salmonella* on pork at traditional shops (generalized linear mixed-effects model).

Variables	Coefficient	95 % CI	p-value
Slaughterhouse (TBC)			
Workers wore boots while slaughtering	−0.78	−1.33 to -0.27	0.004
Workers cleaned floors after slaughtering	−0.49	−0.86 to −0.07	0.02
Workers smoked cigarettes or ate while slaughtering	0.66	0.24–1.09	0.005
Pork shop (TBC)			
Sellers cleaned knives while selling	−0.38	−0.70 to −0.04	0.04
Tables were covered with rough material that was difficult to clean	0.32	0.001–0.61	0.02

Pork shop (*Salmonella* presence)	Odds ratio	95 % CI	p-Value
Number of helpers at the market	0.14	0.04–0.46	0.02
Sellers wore aprons	0.17	0.05–0.51	0.02

prevalence was half of that reported in our recent study (Ngo et al., 2021) and much lower than other findings reported from the partly similar study sites (Dang-Xuan et al., 2019; Nguyen-Viet et al., 2019). Besides the effectiveness of the intervention, the difference in sample size may be another factor that affected the prevalence level. Moreover, the *Salmonella* concentrations before and after the intervention were similar to earlier results at the same study sites (Yokozawa et al., 2016).

Our study once again highlighted the impact of maintaining food safety practices to reduce microbial contamination in pork. The study identified some risk factors related to microbial contamination in pig carcasses and retailed pork. At slaughterhouse level, frequently cleaning the slaughter floor and wearing boots could remarkably reduce microbial contamination. These practices might decrease the microbial population on the floor and reduce cross-contamination from floor to carcass. Although Piras et al. (2014) indicate the importance of cleaning equipment during slaughter, and the participating workers in our study reported a high frequency of cleaning knives at different steps, the regression result did not show any relation between this practice and the TBC in the carcass. This might be due to the lack of disinfection of cleaning tools and equipment since we observed that the slaughterhouse workers and owners did not use chemicals (chlorine for example) during slaughter. An alternative method of spraying carcasses with lactic acid was tested by Van Ba et al. (2019); this may be acceptable to the participants. Besides, the present study revealed an association between unhygienic practice such as smoking while slaughtering and the risk of increased microbial contamination on pig carcasses. The frequency of this practice seemed to increase after the intervention. It could be due to workers perceiving the hygiene was improved and thereby they feel safer to smoke, however this was not further investigated.

At the pork shops, we identified that the use of rough surfaces (such as cardboard or wood) to display pork was a risk factor for bacterial contamination while aprons were effective in reducing *Salmonella* contamination in pork. These results were expected since rough surfaces are difficult to clean could be a source of bacteria while aprons helped to prevent cross-contamination from the seller's clothes or other potential sources of contamination (such as money or other food) to pork. On the other hand, Dang-Xuan et al. (2019) indicated the use of the same cloth to wipe pork, hands and equipment as risk factor so we provided the sellers with different cloths for wiping each item as part of the intervention packages. The result revealed that this practice did not contribute significantly to lower microbial contamination while it motivated the seller to comply with the intervention packages. In addition, our study found the impact of frequently cleaning knives on reducing microbial contamination in pork. This finding was similar to the study by de Freitas Costa et al. (2022) or Swart et al. (2016) which pointed out the contribution of cleaning knives to decreased microbial contamination in pork. However, our study involved only 29 retailers and was likely underpowered to discover smaller improvements. Finally, the presence of helpers at the market was shown to be a positive factor to reduce the probability of *Salmonella* contamination in retailed pork. The helper supports the seller with other activities, possibly enabling or encouraging the seller to focus on the food safety practice. Therefore, the food safety training package for pork shops should consider and involve helpers to boost the reduction of microbial contamination in retailed pork.

5. Limitation of the study

The prevailing COVID-19 pandemic led to the study being conducted over a long period of time. This may have led to some bias in the results of microbial contamination due to the differences in temperature and season. To minimize this, we collected the samples from different objects at the same time (midnight for the slaughterhouse sampling and early morning for the pork shop sampling). Besides, the presence of observers during the operations of slaughterhouses and pork shops could also have affected the participants' practices. Therefore, we interacted with the participants as much as possible so that they would be familiar with our presence. The implementors were also trained and practiced the sampling protocol and the observation checklist to reduce the bias due to the subjectivity of the recorder. Besides, the short period between assessment rounds might not fully evaluated the efficacy of the intervention, especially in long term. But this short period support us to observe the impact of food safety practice on microbial contamination.

6. Conclusion

This is the first study that provides evidence of the effectiveness of food safety interventions in the traditional pork value chain in Vietnam. After intervention, the bacterial contamination of pig carcasses in small-scale slaughterhouse reduced slightly to be comparable to large-scale producers in some high income countries while the *Salmonella* prevalence of pork in traditional shop dropped dramatically. The application of grid-based slaughtering in small-scale slaughterhouses proved to be effective in reducing microbial contamination in pig carcasses. The compliance of slaughterhouse workers and pork sellers with food safety practices was the key to improving the quality of pork. However, the intervention packages should be adjusted and carefully discussed with the participants to get the highest commitment rate, especially about the use of disinfectants in cleaning. This encouraging result should be integrated in scaling programs to improve the safety of pork in Vietnam and countries with similar conditions of pork production and consumption.

Declaration of competing interest

The authors declare they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijfoodmicro.2023.110351.

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