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Evaluating implementation strategies for improved food safety in Vietnam

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Abstract
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Pork is the most popular and consumed meat in Vietnam, and the preference among consumers for fresh and "warm" pork makes the traditional pork value chain dominate the pork industry. This thesis assessed microbial contamination in pork, then evaluated the technical and economic aspects of light-touch interventions in improving the safety of pork in the small-scale value chain. A total of 671 specimens of retailed pork were collected from traditional retail, modern retail, and food services to assess total bacterial count (TBC) and *Salmonella* prevalence. The results showed that 58% of samples were contaminated with *Salmonella*, and 93% of samples did not qualify for the Vietnamese standard of TBC in meat. The contamination of pork was not significantly different between the traditional and modern retail while hygiene practices were associated with lower microbial contamination. Subsequently, light-touch intervention packages were co-designed and implemented at ten small-scale slaughterhouses and 29 traditional pork shops. The packages consisted of providing tools and delivering training for participants. Results showed a reduction of TBC in pig carcasses (from 4.46 to 4.24 $\log_{10}$ colony forming units (CFU)/ cm^2, $p = 0.09$) and *Salmonella* prevalence in retailed pork (from 52% to 24% detection, $p = 0.08$). The upgraded pork shop was then introduced to local consumers in a Becker-DeGroot-Marschak auction game. Consumers showed a strong belief in the intervention at retail stage and were willing to pay 13,000 Vietnam Dong (VND), or 20% higher price, ($p < 0.01$) for each kilogram intervened pork compared to a typical one. This premium payment would cover the investment to upgrade most shops (varied from 421 to 4,146 VND/kg pork). Besides, consuming intervened pork was predicted to reduce annual risk of salmonellosis from 12% to 6%. This reduction could lead to a net benefit of 27,696,241 VND (95% CI: -546,816 – 117,515,493) for consumers and 207,788 VND (95% CI: -38,941 – 658,884) for pork sellers. This thesis provides a sustainable solution to improve pork safety across the small-scale value chain in Vietnam. An appropriate strategy to motivate these actors to implement the light-touch intervention could significantly improve the well-being of community.

Keywords: Food safety, Intervention, Pork value chain, Cost of illness, Cost-Benefit analysis, Microbial contamination, Experimental auction, Salmonella

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“Words have the power to both hurt and heal. When words are both true and kind, they can change our world” - *Buddha*

To my little family with all the struggles we overcame during my study
To my big family and friends who always stay by my side
To my mentors and colleagues who give me support whenever I was lost

List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.

I. Ngo, HTH., Nguyen-Thanh, L., Pham-Duc, P., Dang-Xuan, S., Le-Thi, H., Denis-Robichaud, J., Nguyen-Viet, H., Le, THT., Grace, D., Unger F. (2021). Microbial contamination and associated risk factors in retailed pork from key value chains in Northern Vietnam. *International Journal of Food Microbiology*, 346(2), 109163.

II. Ngo, HTH., Dang-Xuan, S., Målqvist, M., Nguyen-Thanh, L., Pham-Duc, P., Nguyen-Hong, P., Le-Thi, H., Nguyen-Viet, H., Le, THT., Grace, D., Lindahl, FJ., Unger, F. (2023). Assessment of a light-touch intervention to reduce microbial contamination at small-scale pig slaughterhouses and traditional pork shops in Vietnam. Submitted.

III. Ngo, HTH., Dang-Xuan, S., Pham-Duc, P., Nguyen-Hong, P., Le-Thi, H., Le, THT., Nguyen-Viet, H., Målqvist, M., Grace, D., Lindahl, FJ., Unger, F. (2023). Impact of perception and assessment of consumer on willingness to pay for upgraded fresh pork: An experimental study in Vietnam. *Frontiers in Sustainable Food Systems*, 7, 1055877.

IV. Ngo, HTH., Dang-Xuan, S., Målqvist, M., Pham-Duc, P., Le-Thi, H., Nguyen-Viet, H., Le, THT., Grace, D., Lindahl, FJ., Unger, F. (2023). The cost-benefit analysis of a light-touch intervention to improve the safety of pork in Vietnam: The case of salmonellosis. Manuscript.

Contents

Abbreviations

ANOVA	Analysis of Variance
BDM	Becker-DeGroot-Marschak
CFU	Colony forming units
CI	Confidence interval
GMM	Generalized mixed-effects model
HUPH	Hanoi University of Public Health
ILRI	International Livestock Research Institute
LIFSAP	The Livestock Competitiveness and Food Safety Projects
LMM	Linear mixed-effects model
LQMM	Linear quantile mixed model
MPN	Most probable number
NIAS	National Institute of Animal Science
NIVR	National Institute of Veterinary Research
OR	Odds ratio
PERT	Project evaluation and review techniques
SD	Standard deviation
TBC	Total bacterial count
USD	United States Dollar
VND	Vietnam Dong
VNUA	Vietnam National University of Agriculture
WB	World Bank
WHO	World Health Organization
WTP	Willingness to pay

Introduction

Three decades after the economic reforms, Vietnam's economy has steadily grown which led to a dramatic increase in income per capita. As a result, the food consumption of Vietnamese has significantly changed in composition, with reduction in staple food and increase in animal-sourced food (1,2). This trend was more explicit in the case of pork - the most popular meat which accounted for 57% of total meat consumption in 2014 (3). On average, each Vietnamese consumed 29.7 kg of pork in 2019, the third highest consumption after the Chinese and the European (4). In other words, the safety of pork contributes substantially to Vietnamese well-being.

Food safety hazards in pork

Codex Alimentarius defines food borne hazard as "a biological, chemical or physical agent in, or condition of, food, with the potential to cause an adverse health effect" (5). While physical hazards may cause injuries or choking, the effect of chemical and biological hazards to human health are quite complex to infer (5,6). Chemical contamination in pork includes heavy metals, antibiotic residues or growth promoters. These contaminations mainly occur at farm level due to the disobedience of farmers to husbandry regulations or contamination of feed and water sources (7). The Vietnam food safety authorities has banned or set miximum limits for some chemicals in pork, such as lead, cadmium (8), antibiotic residues, and hormone growth promoters in food (9). Biological hazards in pork mainly include parasites and bacteria. Parasites infect live pigs at farm level while bacteria may infect pigs or contaminate pork at any stage of pork production as a result of bad hygiene practices (10–12). According to Vietnam regulations, *Salmonella* is not allowed to be present in pork while the limitation of total bacterial count (TBC) and *Escherichia coli* in pork are 5.7 and 1.7 $\log_{10}$ colony forming units (CFU)/g, respectively (13). TBC is a commonly used indicator of hygiene in food production (14,15).

The World Bank (WB) indicated potential health risks due to pork consumption in Vietnam (16). Consumers have been shown to be highly concerned about chemical hazards in pork (17,18). However, chemical hazards accounted for only 4.2% of food poisoning cases from 2010 to 2020 (19),

likely due to low exposure levels of heavy metals and growth promoters via food consumption (7,20). Besides, the effect of antibiotic residues to human health has not been fully assessed yet (7,12). Therefore, the burden of chemical hazards in pork is likely not as serious as the consumer perceives (16,20).

On the other hand, many studies implicated high levels of microbial contamination across pork value chains in Vietnam. Ngo et al. (21) found the prevalence of *Streptococcus* in slaughtered pig to be 41%, while Ho et al. (22) predicted pork is the source of 25.7% *Streptococcus* cases in human. Furthermore, *Trichinella* and *Taenia* were shown as potential hazards in pig and pork at the underdeveloped and mountainous provinces (23–26). Besides, Nguyen-Viet et al. (27) found 90% and 98% of retailed pork did not qualify the Vietnam standard of TBC and coliform count in meat, respectively.

The high risk of *Salmonella* contamination in pork

Among common pathogens in pork, *Salmonella* is one of the three major causes of diarrheal disease in Southeast Asia (28). *Salmonella* can grow at temperatures between 5-47°C and is eliminated at temperatures over 70°C (29). In some cases, researchers observed *Salmonella* growth in food at 2-4°C although its optimal growth temperature is 37°C (30). Therefore, pork from traditional shops in Vietnam (mostly without cold chain) is a good environment for *Salmonella* contamination and growth (31). Previous studies indicated that *Salmonella* could contaminate pork at any stage across the pork value chain. At slaughterhouse, 15.6% to 69.7% of pig carcasses were contaminated with *Salmonella* (10,11,31–35). At retail, the prevalence of *Salmonella* in pork at traditional markets varied from 26.8% to 72.7% (11,31,33,36–38) while the proportion at supermarkets were 64% to 68.4% (37,39). Pork contaminated with *Salmonella* was found in different areas of Vietnam, which makes it one of the most common hazards to pork consumers. Although cooking pork at high temperature can eliminate *Salmonella*, Dang-Xuan et al. (40) highlighted the risk of *Salmonella* cross-contamination from raw pork to cooked pork during handling at Vietnamese households.

The burden of salmonellosis

In 2017, the estimated number of salmonellosis cases, caused by non-typhoidal *Salmonella* infection, in Southeast Asia, East Asia and Oceania region was approximately 21,500 cases with 1,750 deaths (41). Some common symptoms of salmonellosis include diarrhea, abdominal pain, fever and headache (30). In severe cases, salmonellosis might require long hospitalization, or even lead to fatality in vulnerable groups such as children, elderly or HIV patients (41,42). In the United States, the burden of salmonellosis was estimated to

vary from 3.3 to 4.1 billion U.S. Dollar (USD) for more than 1 million cases in 2009 and 2018 (43,44). Other developed countries including Canada, Australia and Sweden reported the cost of salmonellosis per episode varied from 765 to 6,112 USD. In developing countries, the lack of data and underreporting of cases make the number of salmonellosis cases underestimated and the burden of salmonellosis remains unknown.

Previous studies indicated pork or pork products (such as minced pork, pork burger, sausages, and pork salad) as potential transmission routes of salmonellosis in humans (45–49). The burden of salmonellosis in Vietnam has not been calculated yet, but the high prevalence of *Salmonella* in pork implicates a high economic loss due to salmonellosis. Consuming pork contaminated with *Salmonella* was estimated to cause one to two cases of salmonellosis for every ten Vietnamese consumers annually (33). Reducing microbial contamination in pork, especially *Salmonella*, therefore, may substantially decrease the burden of foodborne illness for Vietnamese.

Pork production in Vietnam: the role of traditional value chain

The emerging economy and large population in Vietnam created a dynamic market for food production and distribution (50,51). In consequence, the number of pork producers are numerous and diverse to meet the need of domestic consumers. The consumer can easily purchase pork and pork products, domestic or imported, from different types of retail (52). Figure 1 illustrates the domestic pork value chain in Vietnam.

According to Hoffmann et al. (53), the small-scale sector dominates the fresh food market in low and middle-income countries. The situation in Vietnam consolidates this statement. The small-scale farms contributed approximately 80% of the total pig supply in 2014 (3). More than half of these pigs were slaughtered in small-scale slaughterhouses, which accounted for 97% of total slaughterhouses in 2016 (54,55). These small-scale slaughterhouses (capacity varying from 1 to 20 pigs/day) often apply floor-based slaughtering with limited equipment or facilities (10,55). The pork is then delivered to consumers via the traditional pork shops in open markets, without preservation equipment such as refrigerator or cool box (3). However, this is the preferred retail for fresh pork where more than 90% of the consumer in Hanoi and Ho Chi Minh City (the two largest cities in Vietnam) purchase pork and pork products (50,51,56,57).

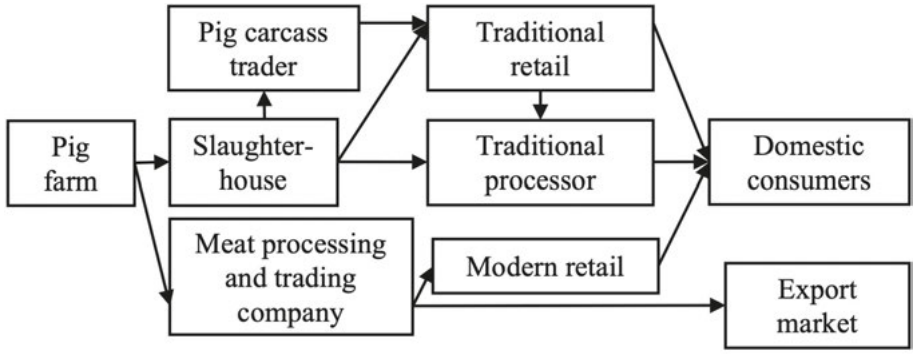

Figure 1. Domestic pork value chain in Vietnam (adapted from Nga et al. (3))

While the small-scale actors rarely form a business contract with each other, the large-scale producers often make written contracts for their transactions (1,52,58,59). The medium and large-scale slaughterhouses (capacity varying from 20 to 2000 pigs/day) usually apply the industrial or semi-industrial slaughtering system to handle pig carcasses which requires a high initial investment (52,60). These slaughterhouses are the main pork supplier for modern retail such as convenient stores or supermarkets, which often are equipped with freezing and cooling facilities to preserve pork products (18,52).

In long term, the Vietnam government aims to control food safety by encouraging the development of industrial-scale pork production and reducing the contribution of the traditional value chain (61). Since 2015, many medium and large companies have joined the pork sector with modern quality management and distribution systems (50). Besides, the modern retail with improved food safety standards saw a rapid rise in the 2010s, especially in big cities (50,62). In the same period, the number of small-scale slaughterhouses has slightly increased while the number of smallholder farms declined in quantity but increased in scale (1,54). In addition, consumer preference for "warm" and fresh pork provides the traditional pork shops a competitive advantage compared to the modern ones (63).

Current policy to improve food safety in Vietnam

The Food Safety Law enacted in 2011 is an effort to adopt the concept of risk-based control via the government, but the lack of public financial and human resources limited its efficiency (1,53). The food safety institutions were also restructured by reducing the involvement of ministries in charge and piloting the new Food Safety Agency (1,16). In addition, the current food safety policies showed a trend to shift responsibility from the authorities to the food producers (28), which means the private sector must find cost-effective measures to upgrade their food safety condition.

The government considers an increase in modern and large-scale food producers as the key to improving food safety in Vietnam, but the dominance of small-scale producers as well as the insignificant improvement in food safety in modern retail make the transition more challenging (18,62,64). Besides, the weak capacity of food safety regulation enforcement also slowed down the effort to reform food production (16,18). In other words, it takes time to gain fruitful outcomes from the government's attempts while improving food safety conditions at small-scale food producers can promptly bring benefit to the community (16,53).

The consumers' willingness to pay for safer products

The consumers' willingness to pay (WTP) for food products can be affected by both external and internal factors. The socio-demographic factors at household and individual levels have been highlighted as significant drivers of the WTP (65–69). In addition, exposure to information about food quality and risk of food products can substantially affect the consumers' WTP, and in many cases, the food label was a useful tool to deliver information to consumers (65,70–73). Besides, consumers' assessment of food products and food stores, especially the hygiene condition, have been identified as important determinants of their WTP (74,75).

In the context of low and middle-income countries, consumers often show a low willingness to pay for food safety (53) but the Vietnamese seem different. Previous studies revealed a high demand of Vietnamese for safe food which motivate them to pay a higher price (76–80). The premium price for safe products such as vegetables, rice, or chicken varied from 9% to 205% compared to the conventional ones. The type of food and the credence of food quality were the main causes of the large variation of the WTP. In previous studies, labeling was used as a tool to inform the consumer about product attributes. However, Vietnamese consumers mostly rely on sensory evaluation (e.g., touching or smelling) to assess the quality of fresh food products (81,82). In other words, these studies might not precisely assess the impact of food quality on consumer's WTP.

In the case of pork, the studies by Hao et al. (83) and Khai et al. (84) showed that 64% to 82% of consumers were willing to pay more for safer products. The premium prices for the proposed pork were estimated to be 38% to 64% higher compared to conventional products (83,84). Stated-preference surveys were applied in these two studies, which might overestimate the WTP (85,86). Besides, in these studies, the consumers did not have opportunity to evaluate the pork attributes following their shopping habit. Therefore, the results might not precisely reflect consumer behavior. In consequence, any investment to improve pork safety based on these results may not be beneficial for all stakeholders.

The potential of light-touch interventions to reduce the burden of salmonellosis

The high demand and alarming microbial contamination levels make it crucial to implement appropriate strategies to improve pork safety in Vietnam. These strategies should optimally cover multiple value chain actors to avoid contamination at any stage (87). However, the lack of evidence on the burden of pork-borne disease and limited options for affordable interventions have prevented policymakers from taking action (16). A few cost-effective measures for *Salmonella* control include detection programs (16,88,89) or herd control (90). These strategies however require high costs and are appropriate for industrial-scale production only (16,53). Other researchers highlighted the limited impact of pre-harvest interventions at farm and suggested conducting interventions at slaughterhouses and post-processing to get the highest benefits (91–93).

The estimated cost of controlling microbial contamination via improving infrastructure in the slaughterhouse was found to be unaffordable for small-scale pork value chains (11,94). For example, implementing steam vacuum and steam ultrasound in slaughterhouses were assessed as cost-effective in reducing microbial contamination (95,96). Nonetheless, the slaughterhouse owners need to purchase the expensive equipment while the consumers and authorities receive the benefits (97). In addition, previous research pointed out that these interventions were not often successful or sustainable (94). Other potential interventions are the use of hot-water decontamination or lactic acid spraying (97,98). Further studies are required to evaluate their feasibility in Vietnam context and the acceptance of consumers for these interventions.

At the retail level, cooling preservation is the most effective measure to reduce microbial growth in pork. But the demand for “warm” and fresh pork are competitive advantages of traditional shops compared to the modern shops (63). Packaging could also be considered a potential solution to reduce contamination. However, the consumer’s habit and reliance on sensory evaluation

to assess the quality of fresh products make it inapplicable (81,82). Changing seller's practices, therefore, becomes the key intervention at traditional pork shops (16). In Vietnam, several general recommendations and guidelines have been developed for pork value chain actors by food safety authorities and programs, such as the standard for the traditional market in 2017 (99), or model slaughterhouses in 2008 (60). However, the current high level of microbial contamination in retailed pork implicated the limited adaption of pork producers to suggested practices.

Light-touch interventions may be the answer to the effort to improve the safety of pork in Vietnam (16,100). This approach focuses on providing food safety training and feasible facility upgrades for participants to create an enabling environment and motivate them to change their behavior at a low cost (101,102). This kind of intervention had been piloted in slaughterhouses and markets in Nigeria and proved to be acceptable and cost-effective in reducing microbial contamination in meat (103). The concern for food safety and willingness to pay for safer pork products of Vietnamese consumers could make it feasible to scale up and maintain the light-touch intervention (104–106).

Aim of the thesis

This thesis aimed to generate scientific evidence about the feasibility of a light-touch intervention and its benefit to relevant stakeholders in the traditional pork value chain in Vietnam. The specific objectives of the study are:

i) To assess the microbial contamination of pork at different retail channels;

ii) To evaluate the effectiveness of a light-touch intervention at the small-scale slaughterhouses and traditional pork shops in terms of reduced microbial contamination;

iii) To estimate the consumers' perception of pork safety and their WTP for a pork product from an upgraded shop;

iv) To analyze the cost and benefit of the light-touch interventions for improving the safety of pork from the perspectives of different stakeholders.

To achieve the above objectives, four corresponding studies were implemented respectively to find the answers.

Methodology

This thesis is part of "Market-based approaches to improving the safety of pork in Vietnam" (SafePORK project), coordinated by International Livestock Research Institute (ILRI) in the cooperation with Hanoi University of Public Health (HUPH), Vietnam National University of Agriculture (VNUA), National Institute of Animal Science (NIAS) and University of Sydney. The SafePORK project funded 70% to 80% of the intervention cost and the remaining was paid by the slaughterhouse owner and pork seller. The thesis consists of four studies, corresponding to the four papers: study 1 assessed microbial contamination of retailed pork; study 2 focused on assessing the effectiveness of light-touch interventions at slaughterhouses and pork shops; study 3 aimed to measure the WTP of consumers for intervened pork, and study 4 analyzed the cost and benefit of the intervention in reducing salmonellosis burden. The research framework of this thesis is illustrated in figure 2 and the overview of applied methods for each study is presented in table 1.

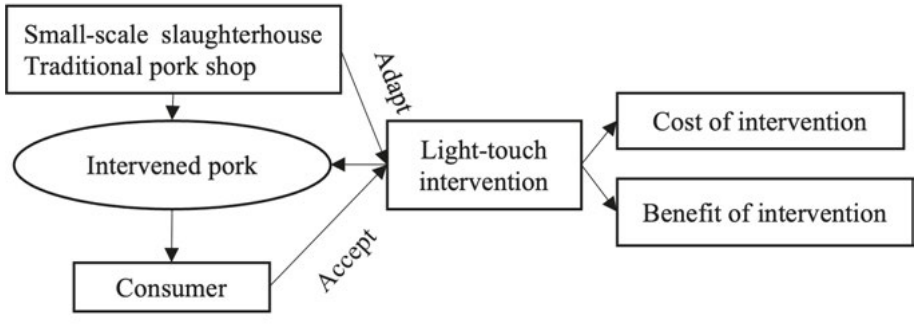

Figure 2. Study framework

Table 1. Summary of methodology applied in each study, where each study corresponds to one paper in the thesis

Study	Study 1	Study 2	Study 3	Study 4
Location	- Hanoi, Hung Yen, Nghe An	- Hung Yen, Nghe An, Hoa Binh, Thai Nguyen	- Hung Yen, Thai Nguyen	
Research objects	- 266 traditional pork shops - 123 modern pork shops - 77 food services	- 29 traditional pork shops - 10 small-scale slaughterhouses	- 152 consumers	
Design	- Cross-sectional study	- Before-after evaluation	- Experimental auction	- Simulation
Main indicators	- Total bacterial count in retailed pork - *Salmonella* prevalence in retailed pork - Food safety condition of shops	- Total bacterial count in pig carcasses and retailed pork - *Salmonella* prevalence in retailed pork - Food safety practice of slaughterhouse workers and pork sellers	- Willingness to pay of consumer - Knowledge, perception about food safety of consumer	- Cost of salmonellosis - Investment to upgrade pork shops - Benefit of pork sellers and consumers
Data collection	- September 2018 to April 2019	- September 2019 to July 2022	- October to November 2021	- Collected data from study 2 and study 3
Data analysis	- Descriptive statistics - Chi-square test - Analysis of Variance (ANOVA) test - Univariate analysis - Logistic regression - Linear regression	- Descriptive statistics - Wilcoxon signed rank test - McNemar test - Univariate analysis - Linear and generalized mixed-effects models	- Wilcoxon signed rank test - Spearman rank test - Linear quantile mixed models	- Monte Carlo simulation - Probabilistic one-way sensitivity analysis

Study sites

Five provinces in northern Vietnam, namely Hanoi, Hoa Binh, Thai Nguyen, Hung Yen, and Nghe An, were selected for the project, but were not all included in each study (Table 1). These provinces represented different components and varieties of pork value chains. Hanoi is the capital and second largest city in Vietnam, representing the consumption area with a diversity of pork value chains including traditional, modern establishments, and food services (107). Hung Yen and Nghe An represented rural area where the traditional small-scale producers dominated the pork industry (108). Hoa Binh was selected as the source of indigenous pork value chain (17), while Thai Nguyen represented both peri-urban and urban setting. Figure 3 illustrates the location of five study sites in Vietnam map.

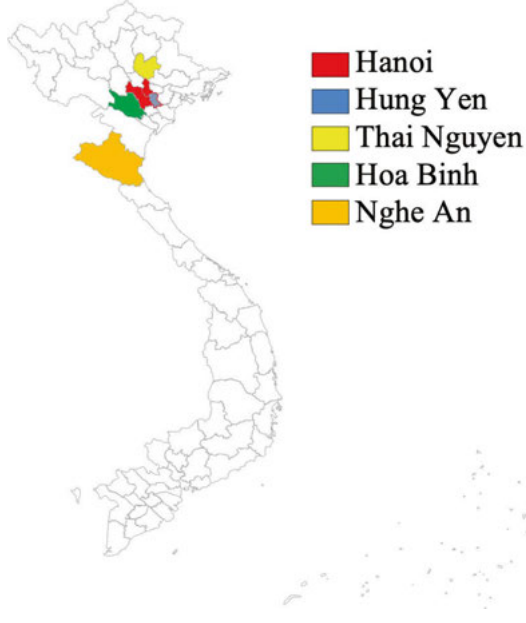

Figure 3. Map of Vietnam with the highlighted study sites

Sample size and participant recruitment

Cross-sectional survey

In study 1, a cross-sectional survey was conducted to collect data about microbial contamination at different retail types, including traditional retail (traditional market and wet market), modern retail (supermarket, boutique shop and convenience store), and food services (canteen and street food). Traditional retail was the main target of the thesis while modern retail and food services were chosen for comparison.

Due to the abundance and diversity of retail types, Hanoi was selected to fully reflect the reality of retailed pork. A list of modern establishments, traditional markets and wet markets from five urban districts were developed for sampling. At each traditional or wet market, two to six shops were randomly selected for sampling. In addition, the traditional pork shops in Nghe An and Hung Yen were chosen according to the link with agriculture production cooperatives. Finally, the food service establishments consisted of street food vendors and canteens in Hanoi. The street food vendors were located in the specialized planned area for street food while the list of canteens was chosen following the local government's recommendation.

To calculate the sample size for modern and traditional retail, the two-proportions comparison was used with the expected *Salmonella* prevalence for each retail type was 45% and 60% respectively. The intra-cluster correlation was set at 0.2 with the average cluster size of 5, and design effect of 1.2. For street food, the single proportion estimation with expected prevalence of 50%, intra-cluster correlation of 0.2 and average cluster size of 3 was used. For canteens, the number of establishments was set up to be at least 20 and the establishments were suggested by the Food Safety and Hygiene Division of Hanoi. Finally, 266 pork samples from 266 traditional shops (one sample per shop), 328 pork samples from 123 modern shops (two to five samples per shop), and 77 pork samples from 77 food services (one sample per establishment) were collected to make up a total of 671 pork samples.

Slaughterhouse and pork shop recruitment

In study 2, two lists of criteria were developed to select slaughterhouses and pork shops involved in the intervention. For slaughterhouses, the capacity, compliance and ability to adapt to intervention were essential. The target of the intervention package was floor-based slaughterhouses with adequate facilities to instead apply grid-based slaughtering including water and drainage systems, and enough space to separate places for exsanguinating pigs or splitting carcasses. Finally, the commitment and volunteering of slaughterhouse owners and workers to join were necessary criteria. The workers then collaborated with the research team to co-design the stainless-steel grid

following the slaughterhouse capacity and the common pig size. In addition, the slaughter area and water system were also re-arranged for convenient use.

For traditional pork shops, the neighbor markets sourcing pork from the intervened slaughterhouses were investigated first to assess the basic facilities to adapt to the intervention package including operating under the market management board and having a separate area for animal-sourced food. Later, a group discussion with the pork sellers was organized to assess their commitment as well as finalize the tool package.

At the beginning of the study, a list of potential slaughterhouses and traditional markets was suggested by the local authorities of five study sites. The research team later planned to investigate all of them to assess the conditions as well as how voluntary the slaughterhouse owners and pork sellers were to participate. However, the spread of COVID-19 pandemic, followed by strict condition of travelling and social distance regulations in Vietnam, prevented the exploration. Finally, 29 pork shops from three markets in Hung Yen and Thai Nguyen, and 10 slaughterhouses in Hung Yen, Thai Nguyen, Hoa Binh, and Nghe An participated in the intervention.

Consumer recruitment and interviews

In study 3, on the day before the experiment, one out of every three consumers of the markets (where the intervened pork shops are located) were invited to participate in an experimental auction game to measure their acceptance of light-touch intervention as well as the pork from upgraded shop. The potential consumers who intended to buy pork and consented to participate in the experiment on the following day were interviewed using a questionnaire. In the experiment, two pork shops were set up so that the participants could make a comparison between typical and intervened shops. The experiment was held on the day off of the intervened markets to reduce the conflict with market operation. At the end of the experiment, the participants would have a chance to purchase pork from one shop only to reduce the demand reduction effect. Each participant would move out of the market area right after finishing the experiment to comply with the local regulation of social distance during the COVID-19 pandemic as well as reducing their interaction with other participants. The sample size was estimated to be 123 participants via using the formulation of Lusk and Shogren (86) with the expected standard deviation (SD) of the bids across products of 20,000 VND, critical effect size of 40% at level of significance of 95%. In total, 152 participants in Hung Yen and Thai Nguyen finished the interview and the experiment.

Light-touch intervention packages

Slaughterhouse

At the small-scale slaughterhouse, the intervention package included upgrading the facility and delivering food safety training session for slaughterhouse workers and owners. In detail, the slaughterhouse was equipped with a stainless-steel grid to lift the carcass from contact with the floor. In addition, the water system was also expanded with new hoses and taps. The training session was delivered later to introduce the workers to the grid-based slaughtering method as well as good food safety practices in pig slaughtering, especially cleaning tools, hands, and floors with the upgraded facilities. Figure 4 shows an example of the upgrades at a slaughterhouse.

Figure 4. Upgraded slaughterhouse with intervention package.

Pork shop

At the traditional pork shops, the package consisted of providing new tools and delivering food safety training for the seller. The new tools included aprons, cutting board, cloths, disinfection liquid, sprayer, and hand sanitation gel. In addition, a poster was set up on the selling table to remind sellers to maintain good practice during sales, with a focus on hygiene practices with the new tools. A training session was delivered later to introduce the seller to food safety practices at retail level. Figure 5 illustrates an intervened pork shop.

Figure 5. Upgraded pork shop with intervention package.

Data collection

Study 1 was conducted as a one-time cross-sectional survey, where the data collection occurred before the commencement of the work with this PhD thesis. In study 2, three rounds of assessment were implemented across six implementation weeks of light-touch intervention. The first round was conducted one week before the implementation, the second round was in the middle of the third and fourth week after the first visit, and the third round was in the sixth week. To reduce the impact of season and temperature on microbial results, a period of six weeks was chosen while the sampling time during the day was almost the same across three rounds. Figure 6 illustrates the sampling period of study 2. Study 3 included one interview, and then the experiment auction the day after. Study 4 had no additional data collection.

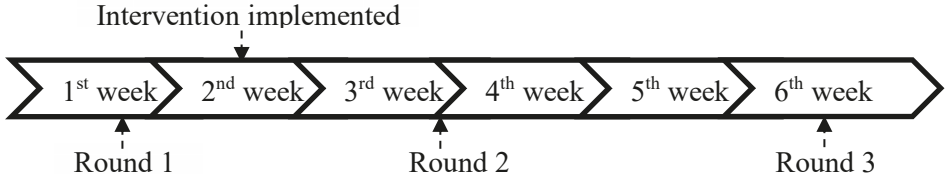

Figure 6. Timeline for light-touch intervention assessment

Microbial and food safety practice data

In study 1, the raw pork samples (approximately 300 to 400 grams) were aseptically collected and then transported to the lab within three hours for processing. The samples were preserved in cool boxes with ice packs all the time during this procedure. A checklist was used to record the sellers' practices and shop's conditions.

In study 2, sampling was conducted at each round of assessment. For each round at the slaughterhouse, the inner half carcass surface (400 cm^2 from four positions), the slaughter floor (100 cm^2 at the splitting spot), and the worker's hand were swabbed for total bacterial count (TBC) testing. At pork shop, the cutting board surface (25 cm^2) and seller's hands were also swabbed for TBC testing while retailed pork was sampled for both TBC and *Salmonella* detection. The swab samples were collected to evaluate the compliance of participants to instructed practices as well as to identify the environmental factors that can affect the contamination of pork or pig carcasses. Besides, the compliance of participants with the instructed practices and the food safety condition of the establishments on the sampling day were recorded using observation checklists. The data collection procedure would be started right after the slaughterhouse owners or pork sellers consented to participate in the research.

Consumer willingness to pay

In study 3, an experiment was implemented at the intervened markets to measure the evaluation of consumers to typical and upgraded pork shop. In this experiment, each shop was supplied with 25kg of pork shoulder sourced from the same intervened slaughterhouse. The experiment created a set-up market where the consumer could behave like their ordinary purchasing habits such as touching, smelling, or observing the shop condition and seller's practices to evaluate the quality of pork products. They also had a chance to directly compare the difference between the two types of shop instead of reading descriptions in stated-preference surveys. The full bidding approach Becker–DeGroot–Marschak (BDM) mechanism (86,109) was conducted to collect data about WTP and assessment from consumers. In addition to the experiment, a structured questionnaire was developed to collect data of participants from six components: demographic information, pork preference, the experience of food borne diseases, perceptions about food safety, practices to prevent pork-borne diseases, and knowledge about food safety. The questionnaire interview was conducted the day before the experiment. Figure 7 illustrates the BDM mechanism.

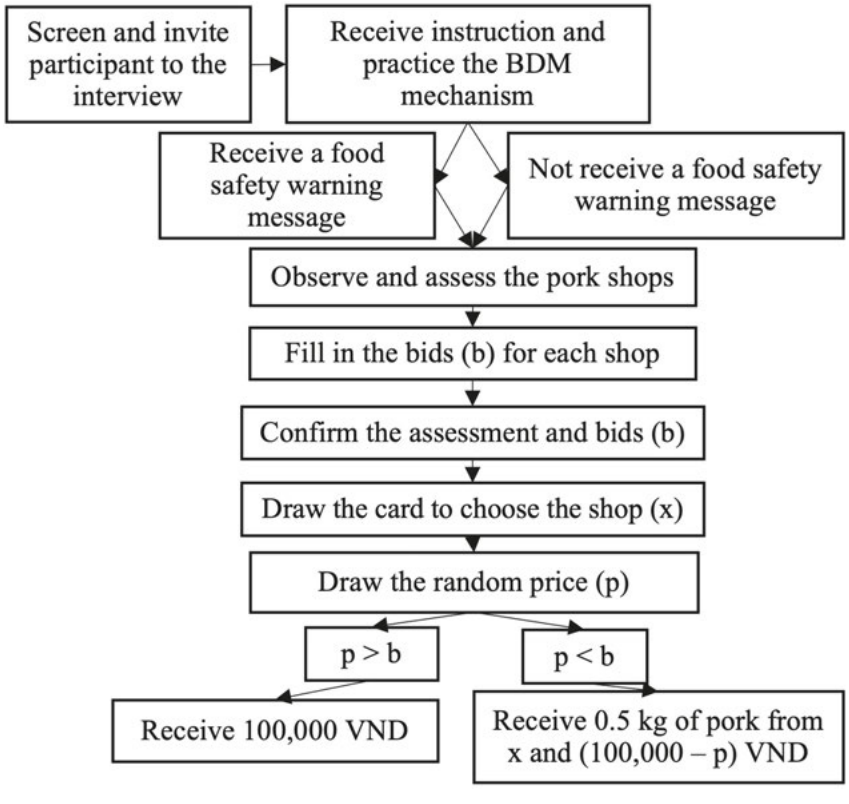

Figure 7. The process of BDM mechanism

Cost-benefit data

In study 4, the cost for the pork sellers was simulated from the total cost of investment to upgrade 29 pork shops with the light-touch intervention packages in study 2. In addition, the benefit of pork sellers was assumed to be the same as the difference in WTP of consumers for pork from upgraded shop and typical shop in study 3. From the perspective of consumers, their cost was assumed to also be the difference in their WTP for pork from two shops in study 3, while the benefit of consumer was the reduction of salmonellosis burden due to consuming intervened pork instead of typical pork. The economic burden of salmonellosis was calculated based on the cost of diarrheal hospitalization in 2013 by Hoang et al. (110) while the probability of salmonellosis was calculated following the model developed by Dang-Xuan et al. (33).

Laboratory testing

In study 1 and 2, the TBC testing followed ISO 4833-2: 2013 procedure (111) using the ten-fold serial dilution (from 10^{-2}, to 10^{-6}) and surface plating technique (two plates for each dilution). *Salmonella* detection procedure was applied followed the ISO-6579: 2017 (112) while the concentration of *Salmonella* was estimated following the 3-tube most probable number (MPN) method. The TBC was used as an indicator of hygiene conditions and practices of slaughterhouse workers and pork sellers while *Salmonella* was the main target food borne hazard of this thesis.

For study 1, all pork samples were analyzed for *Salmonella* presence and a random subset of 123 samples were tested for TBC. For study 2, all collected samples were analyzed for TBC while only retailed pork samples at pork shop were tested for *Salmonella* contamination. Out of the samples tested for *Salmonella* prevalence, half of the samples were randomly selected for assessing *Salmonella* concentration with MPN. The sample analysis was conducted by the National Institute of Veterinary Research (NIVR). The details of samples analyzed are presented in table 2.

Table 2. The total number of microbial samples in each study

Study	Participants	*Salmonella* prevalence	*Salmonella* concentration	TBC
Study 1	Traditional retail	266	-	73
	Modern retail	328	-	50
	Food services	77	-	42
Study 2	Slaughterhouse (3 rounds)			
	- Pig carcass	-	-	60
	- Floor	-	-	30
	- Hands of worker	-	-	42
	Pork shop (3 rounds)			
	- Retailed pork	87	42	87
	- Cutting board	-	-	87
	- Hands of seller	-	-	87

Data analysis

Except study 4, the other three studies applied descriptive statistics (including the mean, standard deviation (SD), frequency, or 95% confidence interval (CI)) to depict the variables' characteristics. In addition, univariate analyses were implemented in these three studies to select variables with p-value < 0.2 for the regression models.

Microbial and food safety practice data

In study 1 and 2, the data of TBC contamination was transformed into $\log_{10}$ colony forming units (CFU) per sampling unit, such as $\log_{10}$ CFU/g for pork samples or $\log_{10}$ CFU/cm^2 for swabbed samples (carcass surface, cutting board surface, or slaughter floor) or $\log_{10}$ CFU/hand for hand samples.

In study 1, the Chi-square test was used to compare the prevalence of *Salmonella* and underqualified TBC (higher than 5.7 $\log_{10}$ CFU/g) across types of pork shops while the Analysis of Variance (ANOVA) test was applied for testing the difference in the mean of TBC. Later, logistic regression and linear regression models were applied respectively to identify the association of relevant predictive factors for *Salmonella* occurrence and TBC in retailed pork.

In study 2, Wilcoxon signed-rank test was applied for comparing mean TBC among sampling rounds of both slaughterhouses and pork shops while the McNemar test was applied for testing the change in *Salmonella* prevalence of retailed pork. Besides, linear mixed-effects models (LMM) and generalized linear mixed-effects models (GLMM) were developed with TBC (in pig carcass and retailed pork) and *Salmonella* existence (in retailed pork) as dependent variables, with shop/slaughterhouse as random effect.

Consumer data

In study 3, the consumer's knowledge score was calculated by adding up the total points of the knowledge test (0 for incorrect response, 1 for correct response) while the consumer's perception of pork shop practice was weighted relied on the type of practice (1-5 for good practice and -5 to -1 for poor practice) before adding up to make the perception score. Cronbach's alpha coefficient was applied to test the internal consistency of each question set about perception, practice and knowledge of participants. Wilcoxon signed-rank test was also implemented to compare the mean of consumers' WTP and assessment for two types of pork shops while Spearman rank correlation test was used to test the relationship between the perception, assessment, knowledge, and attitude of the consumer. Finally, the linear quantile mixed models (LQMM) were used to evaluate the impact of independent variables on the consumers' WTP for pork from different shops.

Cost-benefit data

In study 4, Monte Carlo simulation was applied to generate the cost and benefit data from the intervention input. The project evaluation and review techniques (PERT) distribution was applied for most variables, except the prevalence of salmonellosis severity (categorical distribution) and the cost of salmonellosis (normal distribution for each severity). Probabilistic one-way sensitivity analysis with two-dimensional Monte Carlo simulation was conducted for 10,000 iterations at seven quantile values. The net benefits of each stakeholder were described as the equations below:

$$B_s = \left(\Delta_{wtp} - C_i\right) \times Q_s \qquad (1)$$

$$B_c = C_s(p_t - p_u) - \Delta_{wtp} \times Q_c \qquad (2)$$

$$B_i = C_s(p_t - p_u) - C_i \times Q_c \qquad (3)$$

Where:

- B_s, B_c, and B_i are the annual net benefit of pork sellers, pork consumers, and the light-touch intervention in general (VND per year);
- C_i is the average cost of the light-touch intervention to upgrade each kilogram of pork (VND per kg) and C_s is the average cost of salmonellosis for each severity level (VND per case);
- Δ_{wtp} is the difference in willingness-to-pay of consumers (VND per kg) for every kilogram of intervened pork compared to typical one;
- Q_s and Q_c is the quantity of pork that the shop sells, and the consumers eat for one year (kg per year), with the assumption $Q_c = Q_s$;

- p_t and p_u are the incidence rates of salmonellosis annually (% case per year) due to consuming typical and intervened pork, respectively.

This thesis did not observe changes in sale volume after intervention, so the current data of the pork shop was used to estimate the cost and benefit. All datasets were entered in Microsoft Excel and analysis using R (113).

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). All the potential participants were informed about the project. Verbal consent was obtained from each participant before conducting interview, implementing the intervention, sampling, and observation. The identity of all participants was coded before electronic data storage and analysis. Only authorized staffs had access to the data.

The research project is not expected to have had any negative impacts on the slaughterhouse or market profitability and operation or have had any negative effects on participants. Pork retail in the traditional sector is female dominated in Vietnam, and it is thus expected that most gains from the project would benefit women. On the other hand, most of slaughterhouse owners and workers are male who would enhance food safety knowledge from the project. It could be argued that improving the traditional retail sector could work against the strategy of the government to strengthen the formal retail sector, but since the informal retail sector is unlikely to disappear, improvements in traditional markets are necessary to safeguard public health. All project activities were informed and approved by the local authorities in advance. During the COVID-19 pandemic, the project team and participants complied with the local regulations about equipment and physical distancing in group events.

Result

Microbial contamination of retailed pork at different value chains

At traditional retail, 80.5% of pork was sourced from slaughterhouses or self-slaughtering, and it took an average of 47 minutes (SD: 26 minutes) for transporting 57 kg pork (SD: 31 kg pork) to the market. While most shops had cloth for wiping pork (86.8%) and most sellers wore an apron (71.1%), only half of them had water for cleaning. Washing soap (3.5%) and cooling facility (1.9%) were rarely observed at the shop. About one-third of shops had stagnant water or waste in the surrounding area. Half of the shops placed the pork in proximity to raw organs or other meats, and only 1.1% of shops covered the pork. In comparison, 95.1% of modern shops were equipped with cooling facilities. A large proportion of modern shops (74.8%) placed the pork in proximity to raw organs or other types of meat but in almost all cases (95.9%) the pork was packaged.

The results revealed a high microbial contamination level of retailed pork across different retail types. Overall, 58.1% of pork samples were contaminated with *Salmonella* (60.5% for traditional retail, 50.9% for modern retail and 80.5% for food services) and 93.8% of samples did not meet the Vietnamese standard for TBC (97.3% for traditional retail, 88% for modern retail and 94.6% for food services). The contamination at traditional pork shops was not significantly different from modern retail for both *Salmonella* and TBC (6.54 ± 0.64 log CFU/g vs 6.38 ± 0.65 log CFU/g, respectively).

At traditional pork shops, the use of separate cloths to wipe pork and equipment could reduce the possibility of *Salmonella* contamination (odds ratio (OR) = 0.35, 95% CI: 0.13 – 0.96) while the presence of sewage or stagnant water surrounding the shop might increase *Salmonella* contamination in pork (OR = 2.1, 95% CI: 1.01 – 4.34). In addition, an increase of 10 minutes of transportation significantly increased the TBC contamination by 0.09 log CFU/g. At modern pork shops, increasing storage temperature by 1°C increased the risk of *Salmonella* contaminated in pork (OR = 1.31, 95% CI: 1.04 – 1.65). Besides, selling only pork was associated with decreased prevalence of *Salmonella* in pork (OR = 0.14, 95% CI: 0.03 – 0.64) compared to selling more than one type of meat.

Effectiveness of light-touch intervention at small-scale slaughterhouses and traditional pork shops

The intervened slaughterhouses slaughtered one to six pigs per day with two or three permanent workers. Nine out of ten slaughterhouses operated with the participation of local pork sellers. For the pork shop, almost all participating pork sellers (96.6%) were female and half of them were supported by family members in pork selling. The pork sources were often close to the markets, and on average, it took the pork seller approximately 12 minutes to transport pork from slaughterhouses to the market, and on average each seller sold 43 kg pork products per day. The time and distance to transport pork in study 2 was much lower than in study 1, although the amount of pork per day was not much different.

At the slaughterhouse, the average TBC contamination on pig carcasses after intervention reduced slightly from 4.46 log CFU/cm^2 (round 1) to 4.23 log CFU/cm^2 (round 2) and 4.37 log CFU/cm^2 (round 3). Besides, the workers showed significant improvement in the frequency of cleaning tools and surfaces such as knives (45% in round 1 to 65% and 90% in round 2 and 3), all floors after finished slaughtering (35% in round 1 to 65% and 80% in round 2 and 3), slaughtering floor or grid after splitting carcass (45% in round 1 to 65% and 90% in round 2 and 3). However, the frequency of hand washing was unchanged across three observation rounds while smoking during slaughtering gradually increased. In addition, the regression results revealed smoking during slaughtering process was an associated factor that increased TBC contamination in pig carcass with 0.6 log CFU/cm^2 (95% CI: 0.12 to 0.96), while wearing boots and cleaning the floor after slaughtering significantly reduced the TBC contamination with 1.04 log CFU/cm^2 (95% CI: -1.50 to -0.26) and 0.53 log CFU/cm^2 (95% CI: -0.83 to -0.01), respectively.

At the pork shop, the TBC contamination of retailed pork after intervention reduced insignificantly from round 1 (5.47 log CFU/g) to round 2 (5.34 log CFU/g) and round 3 (5.36 log CFU/g). For all three rounds, 41.38% of samples did not qualify the Vietnam standard for TBC (5.7 log CFU/g). This proportion was half compared to the result from study 1. In addition, the TBC of retailed pork in three rounds was 1 to 1.2 log lower than the TBC at traditional retail in study 1 (6.51 log CFU/g). Compared to study 1, the prevalence of *Salmonella* in pork before intervention was similar to the prevalence at traditional retail (60.5%), but declined dramatically after intervention, from 52% in round 1 to 28% and 24% in round 2 and round 3, respectively. The observations showed that the sellers regularly used the provided tools, including apron (from 62.1% in round 1 to 89.7% in round 2 and 3), or cloths (from 3.5% in round 1 to 41.4% and 55.2% in round 2 and 3). The frequency of wearing apron after intervention was a bit higher than the proportion in study 1 (71.1%), but it was lower at the start. Furthermore, the frequencies of cleaning contact surfaces were also increased, such as table surface (from

44.8% in round 1 to 79.3% and 55.2% in round 2 and 3), hands (from 0% in round 1 to 55.2% and 75.9% in round 2 and 3) and cutting board (from 0% in round 1 to 51.7% and 44.8% in round 2 and 3). On the other hand, the regression results indicated wearing apron was a significant factor that reduce both TBC contamination with 0.45 log CFU/g (95% CI: -0.79 to -0.12) and probability of *Salmonella* contamination (OR: 0.13, 95% CI: 0.02 – 0.72) in pork. Besides, having a table with rough surface was associated with higher TBC contamination in pork with 0.57 log CFU/g (95% CI: 0.22 to 0.91). Interestingly, the support from family members (OR: 0.04, 95% CI: 0.00 – 0.43) was associated with reduced probability of *Salmonella* contamination in retailed pork.

Consumer's perception and assessment on light-touch intervention and their willingness to pay for intervened pork

The customers at the intervened markets were mostly female (90.1%) with a budget of 102,000 VND per day for the food consumption of a four-members family. On average, they frequently consumed 6.44 pork dishes per week and purchased 1.08 kg of raw pork per shopping round.

Overall, the consumer showed a strong belief in the effectiveness of light-touch intervention packages at small-scale producers. More than half of respondents trusted that the grid-based slaughtering method can improve the quality of pork. In addition, more than 80% of respondents believed instructed practices at intervened pork shops would help promote pork safety. As a result, they evaluated the food safety condition at the intervened shop much better than the typical one (9.3/10 vs 7.6/10). However, half of the respondents thought that the use of rough material (wooden table or cardboard) to display pork would improve pork safety. The intervention result in study 2 showed the opposite since this practice significantly increased the TBC contamination in retailed pork.

The result of the BDM experiment showed consumers' preference for the upgraded shop and intervened pork. They were willing to pay an average of 6,500 VND per 0.5 kg (20%) higher for the intervened pork compared to the typical one. The difference in shop assessment strongly affected the WTP in all quantiles while the number of pork dishes per week and the perception about food safety practice at pork shop only showed impact from the 60th and 90th quantile upward.

Cost and benefit of the light-touch intervention package at pork shop

The average annual cost to upgrade the pork shop with the light-touch intervention was 1,801 VND per kg pork (95% CI: 421 to 4,46 VND/kg pork) while the average cost of salmonellosis in Vietnam was estimated to be 345,769,486 VND per case (95% CI: 42,422 – 8,533,563,472 VND/case), approximately 14,936 USD per case.

By consuming the pork from intervened shops, the annual salmonellosis risk for consumers reduced from 12.3% to 6%. As a result, the light-touch intervention brought the consumer an annual net benefit of 27,696,241 VND per year (95% CI: -546,816 – 117,515,493 VND/year), with 61.2% of cases being profitable. The estimated average benefit for pork seller was 207,788 VND per year (95% CI: -38,941 – 658,884) with 93.2% benefit cases. In total, the net benefit of the light-touch intervention was 27,904,030 VND per year (95% CI: -43,292 – 117,762,555) with 59.6% of profitable cases. The sensitivity analysis result showed the annual benefit to the consumer, and the intervention was strongly affected by the cost of salmonellosis, followed by the probability of salmonellosis after the intervention. The annual benefit of pork sellers was mostly influenced by the difference in WTP for intervened pork and the amount of sold pork.

Discussion

This thesis reconfirmed the high level of microbial contamination in retailed pork from all types of retail and suggested that a light-touch intervention can be a potential cost-effective solution to sustainably improve the safety of pork from traditional value chain in Vietnam.

The results revealed a high prevalence of *Salmonella* and TBC contamination in the most common pork value chains in Vietnam. These findings consolidated the persistence of microbial contamination in retailed pork compared to previous studies from 2005 to 2018 (11,27,36,37,39,64,114,115). Among three retail types in this thesis, raw pork from food services had the highest *Salmonella* prevalence, and this was higher compared to the prevalence from food services in different countries such as Taiwan, Philippines, Thailand, or Madagascar (116–118). This result implicated poor practice of food handlers in street food stalls or canteens. In addition, modern pork retail did not show any distinction in microbial contamination level with pork from the traditional retail in both *Salmonella* prevalence and TBC concentration, despite the differences in facilities and preservation condition. Contamination at the slaughter stage might be the explanation for this finding, but it also highlighted that modernization pork retail might not immediately improve the safety of pork. In addition, the use of different cloths for wiping both pork and tools, the hygiene condition around the shop, and transportation time were important factors that should be considered in any intervention packages at traditional retail.

Technically, the light-touch interventions showed their potential to reduce microbial contamination in both pig carcasses and retailed pork, but they still have space to be improved. At the pork shops, the provided tools, including apron and cloths, contributed to the reduction of *Salmonella* prevalence after intervention. The proportion of *Salmonella* presence in intervened pork was half of the figure before intervention, the result in study 1, or the study by Dang-Xuan et al. (11) (44.7%) in the same province. Besides, the sellers were adapting well to the intervention package, indicated by the increasing frequency of good practices. Nonetheless, the use of disinfectant was limited and the TBC contamination in pork was not significantly improved. Although the proportion of samples qualified by the Vietnamese standard was higher than study 1, this proportion was the same before and after intervention. The differences in time and distance to transport the pork between two studies might be the explanation since study 1 found that increasing transportation time was

associated with an increase of TBC. Furthermore, the concentration of TBC in pig carcass and retailed pork after intervention was 0.5 log lower than the finding in the study of Nguyen-Viet et al. (27) in the same province. On the other hand, the regression results also pointed out that displaying pork on rough material such as a wooden table or cardboard significantly increased TBC contamination in pork. This practical evidence should be delivered to pork sellers to convince them to change to smooth and easy-to-clean material. Study 1 as well as the study by Dang-Xuan et al. (11), highlighted that using different cloths to wipe pork and tools might contribute to the reduction of *Salmonella* contamination, but the result in study 2 showed this practice had no impact. Further studies are required to clarify this difference.

At the slaughterhouse, the grid-based slaughtering method showed its impact on reducing TBC contamination on pig carcasses. The contamination after intervention was comparable to industrial-scale slaughterhouse (98,119–122). Besides, the concentration of TBC on the floor surfaces was reduced by 1.5 log after intervention, to be lower than the figure from industrial-scale slaughterhouses in the study of Di Ciccio et al. (121). The explanation for these changes, similar to the pork seller, was the adoption of the instructed practices by the slaughterhouse workers. They frequently cleaned the tools and floor, which is essential to decrease microbial concentration in pig carcasses. However, the frequency of hand washing did not change, while smoking during slaughtering in fact become more common. The latter is a noticeable practice since the regression result revealed that it increased the TBC contamination on pig carcasses, and more information to slaughterhouse workers may be needed to stress this risk.

From the consumers' perspective, the intervention packages could significantly help improve the safety of retailed pork, which was reflected in that they evaluated the food safety condition of the intervened shop higher than the conventional one. As a result, they were willing to pay 20% more for the intervened pork compared to typical one. This figure is three to four times lower than the result from previous studies (83,84). The implementation of an experimental approach, which motivates consumers to reveal their true WTP (123,124), might be the explanation for this difference. However, the consumers would require appropriate signals (such as shop appearance) to recognize the difference in attributes between upgraded shop and conventional one. Interestingly, the consumer revealed a high concern about consuming contaminated pork, but the risk message about salmonellosis risk due to consuming contaminated pork did not affect their WTP. The confidence in handling pork at home might be the reason for this finding. In addition, consumers tended to be willing to pay more for intervened pork in case there was an elderly member in their household. This finding is consistent with the result from other studies (84,125) and implicates the elderly could contribute substantially to the drive to reduce the burden of pork-borne disease. However, consumers still had a misperception about the impact of using rough material to display

pork. The intervention result showed the opposite that rough material was a risk factor to food safety, and this misperception of consumer needs to be adjusted or it might be an obstacle to prevent the food safety practice improvement of pork sellers. In addition, the belief of consumer of the benefits of the grid-base slaughtering method was a good signal. Previous studies implicated that the consumers were willing to pay higher when newly introduced technique are applied in food products (126,127). Therefore, the application of grid-based slaughtering should be informed to the consumer as an attribute of intervened pork products.

This thesis is the first study to estimate the cost of salmonellosis in Vietnam. The figure was quite high compared to developed countries (88,128–130) due to the difference in methodology and the estimated fatality rate. In contrast, the cost of the intervention was comparable to other large-scale strategies to improve the safety of pork (89,90). However, this light-touch intervention did not require a high investment at the beginning, which makes it feasible for small-scale producers in Vietnam. Moreover, the 20% premium price of consumers for the pork from upgraded shop would in most cases cover the cost of the light-touch interventions.

Overall, the benefit of the intervention was mostly transferred to the consumer, especially the groups that are most vulnerable to salmonellosis. But in most cases, the intervention brought a small profit to the seller. This result suggests the sustainability of light-touch intervention since many strategies to control *Salmonella* contamination in pork were estimated to be not cost-effective for both producers and consumers (89,97,131), or applicable only for large-scale pork production (88,96,132). However, the net benefit of the pork seller was strongly affected by consumers' decision (WTP and amount of consumption) while the net benefit of the consumers was driven by the cost and probability of salmonellosis. In other words, the consumers must be the key target of any effort to increase demand for improved safety of pork.

This thesis had one major limitation that it did not include the effect of season on the microbial contamination. In study 1, this effect might not be significant since the pork samples were collected mostly in the winter season but the prolonged implementation in study 2 might affect the microbial result due to the season effect. Another limitation is the impact of COVID-19 pandemic on the consumers' lives and income, which can lead to reduction of their WTP in study 3. Besides, the small sample size in particular in study 2 and study 3 can affect the estimation of cost and benefit in study 4. Finally, this thesis did not include the effectiveness and cost of intervention at slaughtering stages. Previous studies show that this is the most effective stage to control microbial contamination in pork production (91–93). A modified study design, a larger sample size, and longer periods to follow up over different seasons, would be necessary to close these gaps.

Future perspectives

In order to improve the effectiveness of the light-touch intervention, some adjustments should be added to the packages at the slaughterhouse. For example, hanging warning posters around the slaughter area including the use of behavioural nudges as described by Hennessey et al. (100) might be considered to reduce smoking behavior as well as enhance hand-washing practices. Besides, some organic disinfectants, such as lactic acid, should be introduced to slaughterhouse workers and pork sellers to improve cleaning practices. In addition, the packages for traditional pork shops should include providing feasible material to cover the table surface and targeting the seller's supporters in the training session.

This thesis showed the potential of a light-touch intervention to be continued without external financial support. However, an appropriate communication strategy needs to be conducted to inform the consumer about the cost and benefits of the intervention as well as motivate small-scale pork producers to maintain and renew the packages. The vulnerable groups (elderly, children) should be included in this strategy since they are the most beneficial group. Besides, another study is also required to assess the sustainability of light-touch intervention in improving pork safety. Private certification schemes for intervened slaughterhouses and pork shops is also a good option for further expansion.

The thesis also implicated the issue of pork handling at food services which could also be improved via appropriate light-touch interventions. Since the food quality at canteens and street food vendors directly affects a large number of consumers, these establishments should be the next targets of intervention to reduce the risk of salmonellosis. Since the microbial contamination across modern pork value chains was not different from traditional value chains, some feasible solutions (e.g., food safety training for slaughterhouse workers and sellers) should be tested and conducted soon to improve the safety of pork in this growing sector. The identified risk factors in this thesis can be a good contribution to developing training materials.

Conclusion

Improving the safety of pork in Vietnam is a long-term strategy of the government, but mostly targets large-scale production as the key actor. However, the high risk and burden of pork-borne disease make it urgent to investigate the feasible approaches to reduce microbial contamination of pork from the predominant pork value chain. This thesis has implicated the significant potential of a light-touch intervention in sustainably mitigating the cost of salmonellosis for Vietnamese. It not only reduced microbial contamination at different stages of the pork value chain but also could bring economic benefits to both producers and consumers. The investment for the light-touch intervention was affordable but the compliance of participants was essential to make it effective. Besides, the intervention packages were designed in a participatory process and could be adjusted according to the condition of pork value chain actors as well as the suggestion of participants.

Although the sellers were predicted to get profit from the intervention in most of the cases, the authorities need to promote the potential benefit to motivate them to implement it at their establishments. In addition, a small budget should be considered to sponsor the sellers which motivate them to purchase the intervention package. Furthermore, the authorities should consider to frequently deliver updated food safety training to the seller. The food safety enforcement also needed to be strengthened to coordinate and impose the regulations. The involvement of the government is important to trigger and maintain the incentive of seller and the interaction between the pork seller and the consumer should be considered. The awareness and acceptance of consumers to the intervention would be a strong incentive for the seller to improve. Generally, the consumer's response is a substantial driver to create and transfer the benefit to all relevant stakeholders, therefore, enhancing their perception of food safety and the burden of pork-borne disease is necessary to make the intervention successful. An appropriate combination of risk communication strategy and improving food safety practice at home can significantly increase the benefit.

Overall, while large-scale producers need time and effort to deliver safe pork products to the consumer, the implementation of a feasible strategy across the small-scale pork value chain can promptly reduce the burden of pork-borne disease in Vietnam.

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